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PART V] *SECTION A* [VOL. XXVI

SYMPOSIUM ON FLOODS AND THEIR CONTROL: INTRODUCTORY REMARKS

BY PROF. S. GHOSH

(*Head of the Department of Chemistry, University of Allahabad, Allahabad*)

Delivered at the Silver Jubilee Session of the Academy at the University of Lucknow on December 26, 1955

DESTRUCTION of life and property by flood has been known on this globe and has been a menace from very early times. Occurrence of flood is, therefore, not new but what happened this year in the different parts of this country, *viz.*, Kashmir, East Punjab, PEPSU, Delhi, Uttar Pradesh, Bihar, Orissa and Assam is vivid and fresh in our memory. It became more serious as it occurred at many places in the Indo-Gangetic plain which is thickly populated and even our Capital Delhi was in danger for a couple of days because of rising Jamuna. It is no wonder therefore that attention of all concerned is drawn to such havocs caused by the rivers so that the flood menace is mitigated. It is for this reason that the Academy has organised this Symposium so that the various factors which produce flood may be given full consideration and some solution be arrived at so that the country be saved from the ravages of the rivers.

Man's struggle to fight nature and curve it for its own benefit is as old as the history of man himself and attempts to fight the effects of flood have been done from time immemorial. All these old methods were mainly to provide embankments or bunds on the banks of the river and many of such

constructions are still there to protect a town from the destructions by flood. Some of these embankments are as old as may be traced to Hindu period of Ancient India. They are however unable to completely check a flood and protect all the area through which the river flows. It is well known that the River Sorrow of China has reinforcing banks, possibly longest in the world, yet this heroic attempt has not been able to curve the ever-changing course of this frightful river. The whole problem as is now recognised is that the proper method of flood control lies not only in the precautions taken on the plains but also on the hilly tracks through which it flows. The topography of the hills or mountains, the history of the rocks, their steepness, etc., have a great say on the matter of flood. Most of the rivers in Northern India have their origin from a comparatively younger mountain, where the erosion is large. Further, the rains which occur in great downpour within a short period of three to four months add further to the production of floods in our country. Larger erosion means more silt deposition in the plain area where river water moves slow and this means frequent change in river course. The problem is many-sided and construction of multi-purpose dams is also a part of flood control. It may be recalled that the Academy organised a Symposium on Water Power in 1937 and drew attention of the Government to the various utility of dam projects.

I have nothing further to add and I would now request Professor M. N. Saha who, as far as I know, took keen scientific interest in the matter of flood control as early as 30 years back, to occupy the Presidential Chair for this Symposium. I would request him to open the Symposium with his Presidential remarks.

FLOOD CONTROL IN INDIA AND THE ROLE OF HYDRAULIC MODELS IN THE DESIGN OF FLOOD CONTROL WORKS

By D. V. Joglekar, S. C. Desai, S. V. Chitale and S. D. Phansalkar

(*Central Water and Power Research Station, Poona*)

Read at the Silver Jubilee Session of the Academy held at the University of Lucknow on December 26, 1955

1. Flood Damage in Recent Years in India and Efforts Made to Control Them

Inordinately high floods of recent years in India have caused so much destruction and loss of property, and not infrequently loss of life that public today have become very much alive to the problems of river floods. Flood menace is however neither new nor more severe of late than before. Though the floods witnessed this year in Assam, Uttar Pradesh, Bihar, Orissa, Delhi, PEPSU, Punjab and Kashmir have been particularly heavy and brought untold misery to millions and hence are fresh in memory, even before some part or other of the country has always been affected by floods. For instance record of past three years—see Table I—will reveal that flood damage in all these years has been colossal.

Man's struggle to fight and conquer nature is as old as himself and this is equally true of the attempts made to mitigate flood menace in India as anywhere else in the world. These were channelised mainly in one direction, namely, constructing flood embankments on the banks of the rivers. Remnants of the age-old Bir bund on the Kosi, numerous bunds on Ganga and isolated flood banks constructed on several other rivers are indicative of the struggle our forefathers had to give in combating the rivers and their efforts might have proved successful for the time being.

During the British regime, the problem of protection from floods was not totally neglected. Many miles of flood embankments as on the rivers Indus, Damodar and Gandak were constructed so also local and comprehensive training of rivers to provide flood relief was undertaken on many rivers. The importance of flood control having been realised, flood committees and conferences were set up in many Provinces (now States). Several such committees were thus appointed by the Government of Bihar and Orissa. North Bihar Flood Conference was held in 1937, the Inter-Provin-

TABLE I

Showing extent of flood damage in various States, more seriously affected in the years 1952, 1953 and 1954

Year 1952

State	Area affected	People rendered homeless	Village affected	Loss of cattle	Remarks
Assam ..	18,400 sq. miles	30,000	..	..	Assam's worst flood in 18 years
Bihar ..	1,000 sq. miles	..	500	..	..
Punjab ..	..	4,000	35	30,000	..
W. Bengal ..	Town of Jalpaiguri severely damaged	..	..	..	..

Year 1953

State	Area affected	People rendered homeless	Village affected	Loss of human life	Loss of cattle	Houses lost	Loss of crops	Total damage	Remarks
Assam ..	1,200 sq. miles	36,000	137	..	..	10,000	..	..	..
Bihar ..	3,000 ,,	63 lakhs	More than 2,000	4	61	1,00,000	Rs. 20 crores	Rs. 35 crores	..
Madras ..	..	10 lakhs	..	46	100	..	..	Rs. 50 crores	Godavari flood highest in 50 years
U.P. ..	605 sq. miles	12 lakhs	3,600	..	..	11,000	..	..	..

Year 1954

State	Area affected	Damage of crops	Damage to houses and property	Damage to communications	Loss of human life	Loss of cattle	Total loss	Remarks
Assam ..	12,000 sq. miles	Rs. 9 crores	Rs. 1·4 crores	Rs. 85 lakhs	17	3,094	..	..
Bihar ..	10,000 sq. miles	3·2 million acres	40,000 houses destroyed	..	42	608	..	..
W. Bengal ..	1,900 sq. miles	Rs. 7·5 crores	Many thousands	Crores of rupees	142	1,500	..	..
U.P. ..	2,660 sq. miles	Extensive damage	19,600 houses damaged	..	25	2,000	Over Rs. 6 crores	..

cial Flood Conference was held at Lucknow in 1939 while nine Flood Conferences were held at Cuttack between 1945 to 1949.

With the independence of India, flood control activities have gathered much more impetus. The Central Water and Power Commission fortunately came into being in the same year to whom was relegated the important task of formulation of the various multipurpose river valley projects. In these projects lies the permanent and effective remedy to flood problems. A planned and integrated effort to tame and harness the rivers for multipurpose development was however only made with the drawing up of the First Five-Year Plan. By now, as this plan is being completed, the achievement for flood control is quite significant. The Hirakud Dam Project when completed next year will be able to lower the maximum flood levels in Mahanadi Delta so as to provide perfect control for floods having a frequency of occurrence of 100 years or less. The Damodar River will be controlled after the construction of multipurpose storage reservoirs. The first phase essentially comprises of four dams at Konar, Tilaiya, Panehet Hill and Maithon and a barrage at Durgapur. At present two of the reservoirs are ready, *viz.*, Konar and Tilaiya. When the dams are constructed the flood peaks can be cut down from 10 lakh cusecs to 2·5 lakh cusecs. The Bhakra Dam on Sutlej which is rapidly being pushed through, will achieve appreciable lowering of flood levels in the river below. Other small and big multipurpose schemes too numerous to mention included in the First Five-Year Plan will similarly have direct effect in checking the flooding. Flood control is however only one of the many objectives of these multipurpose schemes. The real urgency of putting up concentrated drive for purely flood control aspect was keenly felt during the tragic devastation spread by 1954 abnormal floods. Bihar, Bengal and Assam were the worst victims and sustained heavy losses similar of which were not heard of before. Government quickly moved to expedite the handling of flood problems with a proper perspective and added a separate flood wing to the Central Water and Power Commission (C.W.P.C.) for investigations, planning and designing of flood control works on a broad countrywide footing. This flood wing now consists of 2 Chief Engineers with several circles and divisions which have already collected a good deal of basic and important data so essential in preparation of such schemes on scientific and sound lines. In addition, another important wing of the C.W.P.C., the Central Water and Power Research Station, has taken up an extensive programme of model experiments in respect of many a major and minor flood control and multipurpose projects like those on the Mahanadi, Kosi and Brahmaputra rivers. Model studies are also underway at the other Hydraulic Laboratories under the individual States and much

useful work has already been turned out. Simultaneously, the Government instituted the River Commissions for the Brahmaputra, Ganga and Punjab, PEPSU-Kashmir and Deccan rivers. In line with the Commissions, the Flood Control Boards have also been formed in different States. The forces have thus been mobilised in sufficient strength to combat the flood menace and the machinery has been set rolling to achieve a complete control over the river floods. For preparation of scientific schemes these Commissions and Boards have first to collect exhaustive hydrological and meteorological data. Beginning has already been made by setting up new Stations for gauging of river water-levels, discharges, their sediment transport. For observation of rainfall and other meteorological data, Meteorological Department is setting up new observation posts, while a heavy programme of conducting the land and air surveys over wide areas was undertaken as required by the Commissions and Boards. Government have assured the necessary funds in the Second Five-Year Plan for implementation of the schemes. In addition, foreign aid under UNESCO, Colombo Plan, etc., will be welcomed.

It will thus be appreciated that efforts to meet the emergency are being brought to bear which hold a great promise and hopes for millions of unfortunate flood-stricken people.

2. Role of Hydraulic Models in Design of Flood Control Works

Voluminous and extensive literature is available on different methods of flood control. Principally they can be divided under the following categories:—

(*a*) Construction of flood embankments along the river banks or ring bunds round important towns, villages, properties and estates to prevent flooding.

(*b*) Natural or artificial flood diversion through subsidiary channels of the parent river, or in another river system or to selected depressions, lakes, etc., with the aim of relieving intensity of floods in the main rivers.

(*c*) Overflow or feeder weirs in the flood embankment designed to overflow at a predetermined flood stage.

(*d*) Detention and storage or use of existing lakes or else construction of a number of small tanks in the catchments for the purpose of flood moderation.

(*e*) Training of rivers to provide local protection at critical points from erosion, scour or flooding by spurs, revetment, dykes, etc., to form artificial

cuts to lower the flood level and improve river regime, widen and deepen the river-bed artificially by dredging or by other training measures such as bandelling, groynes, etc.

(*f*) Soil conservation in the catchments by various known methods.

(*g*) Preparing detailed plans for mobilisation of the local resources for supervision of embankments during floods, for flood relief works and other emergency measures and to associate local population with such works by way of ' Shramdan ', etc. Collection of materials such as earth bags, stones, brush wood matresses, etc., to reinforce or add to the protective works during flood.

(*h*) Flood forecasting and warning system to keep alert all concerned people in advance and to take timely action for evacuating in case of imminent danger.

The important role played by hydraulic models in the design of any of the above flood control measures will be discussed below:

The technique of hydraulic models has now developed into an advanced science and has been universally acknowledged as an essential aid to designs of any hydraulic engineering structure, scheme or project. Starting with almost a toy model of Siene experimented upon by the end of the nineteenth century in France, the present-day models can utilise as much as 300 cusecs discharge and are spread over extensive area as big as a square mile or more as at Malikpur Research Station of Punjab. The pioneer Indian Hydraulic Research Station, the Central Water and Power Research Station (C.W.P.R.S.) was started in 1916 at Poona. The progress and achievements of this Institute were so spectacular that additional similar laboratories were quickly set up and by now facilities of hydraulic model testing are made available at 11 research centres spread over the whole of India. The advantages of this new science making it so popular among the engineering profession are that model testing is extremely cheap, yields reliable results, gives qualitative and very often quantitative design data with remarkable accuracy and lastly many times in absence of any better guide, engineering designs have got to be made on basis of model tests alone.

Field covered by hydraulic model experimentation is very wide. They are employed in connection with irrigation schemes for efficient sand exclusion from irrigation channels taking off at the weirs and barrages; in navigational problems such as design of locks, docks, harbours, maintenance and improvement of navigational channels, design of breakwaters, lighthouses, dredging scheme and operations, damping of ranging inside harbours, etc.; in ship-

building industry for design of hull forms of ships and their lines, propulsion tests, estimation of power required, propeller design, testing of manœuvrability of ships, etc.; in hydro-electric or multipurpose schemes for design of penstocks, surge tanks, turbines, tail race channels, dam structures such as conduits, sluices, gates, valves, spillways, energy dissipation devices, etc.; in water-supply projects for design of water intake structures, sedimentation or settling tanks and conveyance of water; in flood control programmes for design and testing of diversion schemes, safety of flood embankments, estimation of probable rise of water-levels by provision of dykes and protective works required for them, operation of storage dams for regulation of the flood levels in an interconnected system of the river and its tributaries and for assessment of the changes in the river regime which would result on adoption of the particular scheme; in river training schemes; in designing of bridges and so on. In other words, there is not a branch of hydraulic engineering wherein this science cannot be advantageously utilised.

Obviously there are certain laws governing technique of model experimentation. These depend on the forces involved in the particular phenomenon under study. The forces are either due to gravity, viscosity, surface tension or elasticity. On account of practical difficulties of satisfying the conditions essential for reproduction of all of these forces simultaneously in any hydraulic model, a theoretically perfect solution is often not possible. Thoroughly sound and very accurate results can however always be obtained by accepting certain compromises. These are in the shape of either exaggerating the vertical scale in comparison with horizontal scale, tilting of the model tray, controlling the injection of the sediment load, altering the bed and side friction by using different materials, or resorting to artificial roughening, choosing the proper fluid such as water, other liquids or else air, adjusting the pressures and velocities as in water runnels and cavitation tanks and by applying several similar contrivances.

Restricting now the discussion to only flood control problems, all the different methods of flood control in practice enumerated previously have immensely benefited the Engineering profession by subjecting the projects prepared in design office to model tests. Illustrations to amplify this really abound and hence only a cursory mention of some of these are made here.

An interesting series of experiments were conducted recently at the Bengal River Research Station in connection with a flood embankment scheme which finally settled the controversies regarding the baffling inconsistencies in the flood water-levels of the Konar River which were adopted

in the Bokaro Thermal Power Station Project of the D.V.C. Very important model investigations are underway at the Poona Central Water and Power Research Station in connection with Kosi flood embankments. In addition, a scheme for flood diversion forms a crucial part of this project and this aspect is also under study in the models. Similar diversion works on the Mahanadi at and below Naraji are also being intensively examined at present at the Poona Station.

Training of rivers by spurs, embankments, guide banks, revetments, cut-off channels and by other control structures has always been a special line of hydraulic experimentation in which Indian Laboratories have especially marvelled. Instances are too numerous and well known to need any mention.

It may be interesting to know that even a subject like Soil Conservation has lately been handled by experimenters. Valuable quantitative data under controlled conditions could thus be collected and insight into these problems was obtained. Contribution which deserves special mention is that made by Handa in India, Musgrove in U.S.A. and by Vank Dijk and Vavelzang in Indonesia.

It is now proposed to present short reports of the two typical experimentation programmes undertaken at present at the C.W.P.R. Station, Poona, in connection with the river projects of the Kosi and Brahmaputra Rivers.

Model Experiments for the Kosi River Project

The Kosi, known as Kausaki in Sanskrit literature, is one of the most well-known ancient rivers of India. Rising in Tibet in the great Himalayan ranges at a height of about 18,000 ft., with the highest peaks in the world Mount Everest and Mount Kanchenjunga lying in its catchment area, the Kosi joins the Ganga near Kursela after traversing about 450 miles along Po Chu, a tributory of Sun Kosi. It debouches into the plains below the Chatra gorge and is called Sapt Kosi from the fact that seven streams join together to form the main Kosi channel. Below Chatra the river runs in a sandy alluvial plain and winds its way southwards through a region covered by a number of interplacing channels. The Kosi is known for the huge quantities of sand and silt which it carries down during floods. In the river channels the bed is rising gradually on account of the huge sediment transported (see Photo No. 2105) so that when it is swollen by floods it cuts through the friable banks and seeks new channels in the low-lying inland delta. During the last 100 years it has been changing its course over 70 miles in a westerly direction.

The Central Water and Power Research Station, Poona, in 1941 had prepared a detailed report on factors affecting this westerly translation. These factors were shown to be the east-west slope of the country and excessive sand load carried by the river. The problem of the Kosi was characterised as a threefold problem:

(1) Unconfined and uncontrolled floods devastate vast areas in the flat flood plains by submerging cultivable lands, destroying cultivation, dislocating communication and rendering inhabitants homeless only to face the consequent famine and pestilence. The damage caused by this way every year is unestimable not to mention the sufferings of the people.

(2) Huge quantities of sand brought down by the floods are deposited over fertile and cultivable lands converting them totally into arid zones.

(3) The general course of the river is gradually shifting westwards without sparing anything that comes in its way. The entire population in the flood areas live in a constant danger of being uprooted by the river at any moment.

The Central Water and Power Commission from 1947 onwards collected the data and made exhaustive studies of the problem which culminated in the drawing up of a comprehensive plan for controlling of floods in Kosi. Briefly stated, the proposals in their first phase consist of constructing a barrage at Hanumannagar 30 miles downstream of Chatra and flood embankments on both sides of the river, the right embankment extending from Hanumannagar to Jhamta 70 miles downstream and left embankment from opposite of Belka hill 19 miles upstream of the barrage to 58 miles downstream of Hanumannagar. The barrage would serve as a controlling structure and enforce some amount of control on the steep gradients in the upstream reach of the river. Through diversion sluices of the Hanumannagar barrage 75,000 cusecs discharage would be diverted to the old channels of the Kosi joining the main river in the lower reach. Irrigation is also proposed to be provided to 13·97 lakh acres in Bihar from Hanumannagar barrage and 1·82 lakh acres in Nepal from an open-head canal from Chatra. Irrigation to the extent of 6 lakhs acres at a later stage on the western side of the Kosi river by means of Western Kosi Canal which will be constructed later is envisaged. Possibility of electric power generation to the tune of 20,000 KW on East Kosi Canal is also envisaged. Recourse would have to be made to spurs and groynes along the right bank of the river in the reach from Belka to Hanumannagar for preventing caving and erosion of banks. Below Hanumannagar the river channel would require dredging and straightening to make it flow in a defined deep channel. The flood embank-

ments in this reach will be exposed to vagaries of the shifting courses of the river and protective measures will have to be provided wherever necessary.

For embarking upon the execution of such a complex and comprehensive plan it was essential to test its various aspects in hydraulic models. This work has been taken up by the Central Water and Power Research Station, Poona. Four different models are in commission to study various features of the project.

Of these the pilot model has got horizontal and vertical scales of 1/2640 and 1/100 respectively and covers the entire Kosi basin from Tribeni to its confluence with the Ganga at Kursela—see Photo No. 1379–81/54. In this model the general scheme of the barrage and flood embankments is being tested. The utility of diversion in the scheme has been a controversial issue required to be examined in the model. Experiments conducted in this respect have provided valuable data of the probable rise in flood levels to be expected at various flood stages if 75,000 cusecs of the flood discharge is diverted out side the embankments. The high flood levels along the embankments at the designed flood stage of 8½ lakhs cusecs and also at super flood of 10½ lakhs cusecs are also determined in this model. The importance of these data in designing of the flood embankments is quite evident.

The second model which is on a bigger scale (1/500 and 1/70) covers the region from Chatra to Tehri Bazar including Hanumannagar near which a barrage has been proposed (see Photo No. 1261–A/54 and 2942–54). In this model the proposed design of Hanumannagar barrage has been tested and modified wherever necessary. The model has been useful in suggesting changes in the original position, orientation and layout of the barrage, design of guide banks, of diversion unit and other details such as divide wall, excluders, canal head regulator, etc. The protective measures for preventing bank caving and erosion of Belka hill and measures in the form of spurs and groynes for preventing the lateral westward movement below Belka hill have also been evolved.

A third model covering the region from 6 miles upstream of Hanumannagar barrage down to Jhamta has also been constructed to the same scale of model No. 2—see Photo No. 2784/54. This incorporates the entire reach in which flood embankments are proposed to be built in the river. The main object is to test and finalise the alignment and spacing of the flood embankments. In addition, the protective measures necessary for them for safety against high floods have also been designed with the aid of this model. The conditions obtaining on account of spreading of construction programme over a number of years and testing the validity of the present project designs

subsequent to any drastic changes in the river regime brought about by yearly river floods are also other important aspects being examined in this model.

The fourth model is a part width geometrically similar model of the Hanumannagar barrage constructed in a 3 ft. wide flume and has a scale of 1/40—see Photo No. 2680/55. The discharge coefficients obtainable with various alternative sections of the weir profile, the water surface profiles, scour upstream and downstream and design of energy dissipation devices are being finalised with the aid of this model.

It will thus be seen that practically all of the important designs of the several features of the Kosi project have been put to model tests. Considerable economy coupled with soundness and safety of structures so also ensuring the efficient and successful working of all the component parts of this scheme will undoubtedly result because of resorting to exhaustive model experimentation.

BRAHMAPUTRA RIVER MODEL EXPERIMENTS FOR PROTECTION OF DIBRUGARH TOWN (ASSAM)

Introduction.—The history of erosion by the river along the water front of Dibrugarh town dates back to 1880 as shown by the available records. The trouble was then ascribed to the Dibru River which joined the Brahmaputra at Dibrumukh about $3\frac{3}{4}$ miles below the town. Since 1913 the river Brahmaputra has been slowly cutting away its south bank so much so that Dibru now joins the Brahmaputra about 4 miles upstream of the town.

Since the time the town is under attack by this mighty river, the rate of erosion has increased. In 1950 after the great earthquake the southern channel of the river became more active and started erosion on a large scale. To study the damage caused by floods during 1952, a committee was appointed by the Government of India. This Committee recommended a revetment 4 miles in length. They also recommended collection of data and model experiments for deciding upon permanent measures. Year 1954 saw the Brahmaputra attack at its worst. The total erosion was over 400 ft. on a length of over 4 miles, the maximum near the Old Circuit House being 800 ft.

Probable causes of erosion.—This severe erosion at Dibrugarh as described above is a result of a number of causes, which though to some extent are interdependent, still have individual contributions of their own.

Though no discharge data is available for this river in the vicinity of Dibrugarh, it is perhaps the mightiest of the Indian Rivers and has sustained floods. The floods begin to rise in May and recede by the middle of October,

the discharge being at a fairly high value throughout this period. The eroding capacity of the river is very high because the velocities vary between about 10–15 ft. per second.

Brahmaputra valley is subject to seismic disturbances of a very high intensity. Depending on the position of the epicentre, the earthquakes change the regime of the river to a very great extent. Firstly, large quantities of rock and earth from the landslides are carried down the various streams into the main Brahmaputra causing a substantial rise in the bed levels and thereby reducing the carrying capacity of the channels. Secondly, the hill sides become devoid of vegetation and thus the run-off increases. This is exactly what happened as result of the great earthquake of 1950. Apart from this particular earthquake, Brahmaputra is a river of the aggrading type, the rise in bed being about 0·1 ft. per year with a similar rise in the high water and low water levels. As a result of the 1950 earthquake there has been a rise of 12 ft. in the bed up to 1954.

The axis of the river is not in the centre of the Khadir, but is so shifted towards the south on the downstream side, that the attack is directed towards Dibrugarh town.

The action under the present set of the river and its southward swing are being helped by the natural slope of the country. On the south the ground is sloping away from Brahmaputra and the area behind the town is low lying. Hence it is necessary to hold the town in order to prevent the river from coming to these low lands and destroying the same.

The experiments.—To evolve suitable protective measures model experiments were initiated at the Central Water and Power Research Station, Poona. The scales of the model are 1/500 and 1/66 and it covers a reach 19 miles upstream and 8 miles downstream of Dibrugarh.

The initial runs of the model showed that the discharge drawn by the river channel adjacent to the town gradually increased. Thus it was thought that any solution of a permanent nature for affording protection to Dibrugarh town must aim at reducing the flow along the southern channels (*i.e.*, adjacent to the town) and also check their tendency to develop. Hence a curved divide wall 7,500 ft. long was tested at different suitable positions. Initially the divide wall showed signs of success but was ultimately thrown out of action and the southern channels still developed.

It was thus clear that training the river so as to make it more favourable at Dibrugarh by measures which would be more or less permanent was not

found possible. Hence the only way of protecting the town was by local protection works.

It may be added here that some experiments were also carried out to see if dredged pilot cuts would develop successfully and thus divert the flow away from the town. The results were far from being hopeful. The main reasons for the failure of these artificial cuts are that the river consists of braided channels and that the arc/chord ratio available is very low, namely, about 1·2.

All the above attempts at evolving permanent solution having failed the only alternative left was local protection works such as spurs, etc. A tentative system of spurs was proposed by Central Water and Power Commission which was tested in the model. As a result of exhaustive tests carried out in this connection a combination of 5 stone spurs (out of which No. 1 is 400 ft. long and others are 200 ft. long) and 15 permeable spurs (each 200 ft. long; as shown in Fig. 3) were found suitable. These works will need constant maintenance particularly in view of the very high velocities, oblique river attack and the general tendency of the southern channels to develop. Further, in order to prevent the danger of outflanking, the protection works may have to be extended upstream as the river is showing some signs of attacking the bank upstream of the protected area.

As the working period at Dibrugarh is limited to only about 4 months, experiments were carried out to see if a part of the work could be deferred to a later date. But the results showed that it was necessary to complete the works in one season. Photo No. 457/55 shows how the current is deflected by the proposed spurs.

Accordingly the work was completed during the working season of 1954–55 and there was no bank erosion during the 1955 floods even though the water-level rose to R.L. 345·00, *i.e.*, one foot higher than the highest flood level ever recorded.

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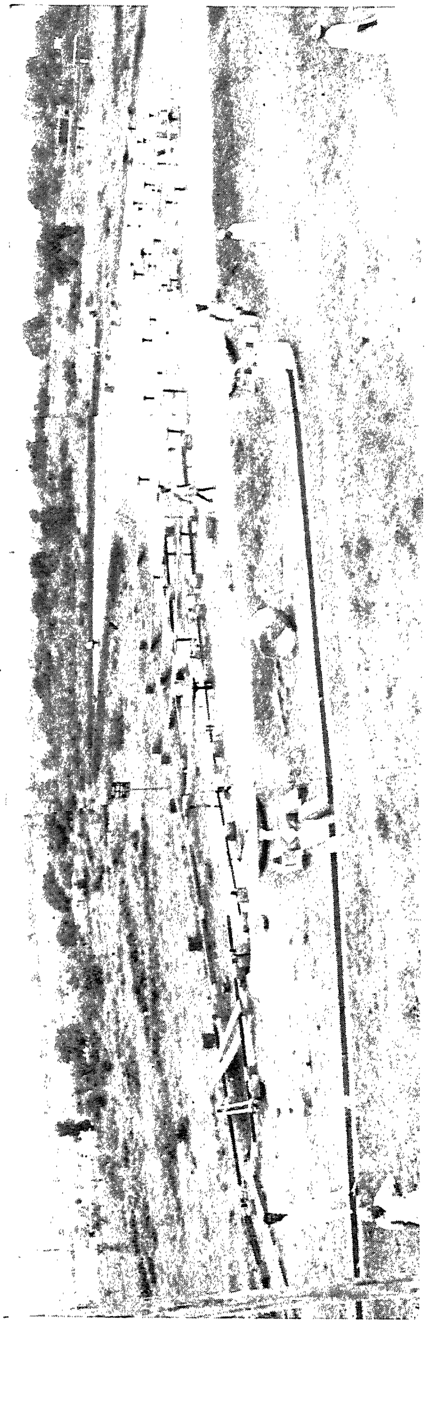

Photo No. 1379–81/54. General view of the model of the whole of the Kosi Basin (Kosi River Model No. 1.)

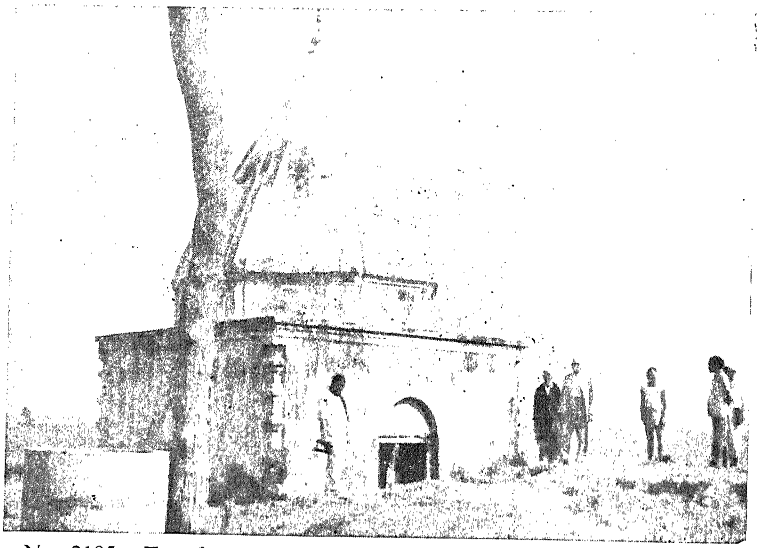

PHOTO No. 2105. Temple near Raharia about 18 miles downstream of Hanumannagar buried in sand upto arch level in two years of Kosi floods, 1951 to 1953.

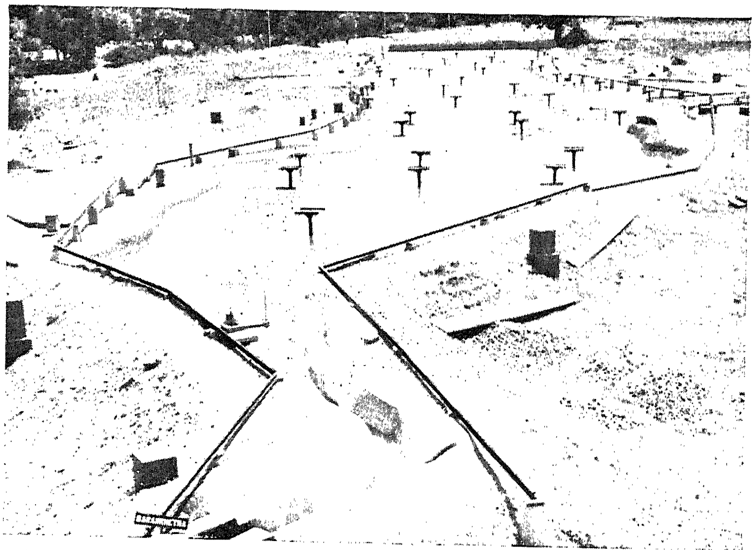

PHOTO No. 1261–A/54. Dry model of the Kosi River reach from Barahakshetra to 6 miles downstream of Hanumannagar barrage (Kosi River Model No. 2).

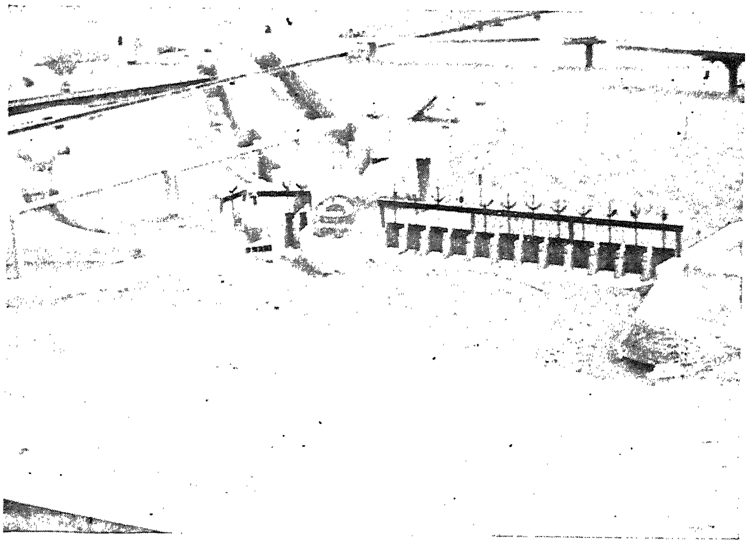

PHOTO No. 2942–54. Close-up view of the Hanumannagar barrage constructed in Kos River Model No. 2.

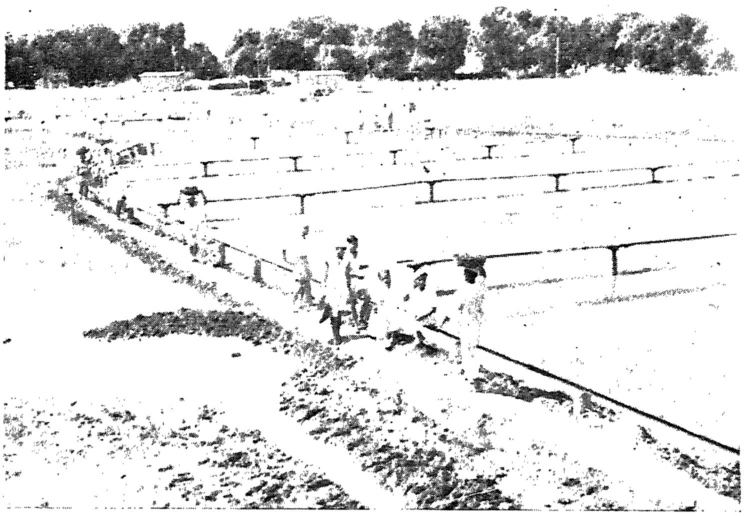

PHOTO No. 2784–54. Kosi model incorporating the river between 6 miles upstream Hanumannagar to end of embankments at Jhamta (Kosi River Model No. 3).

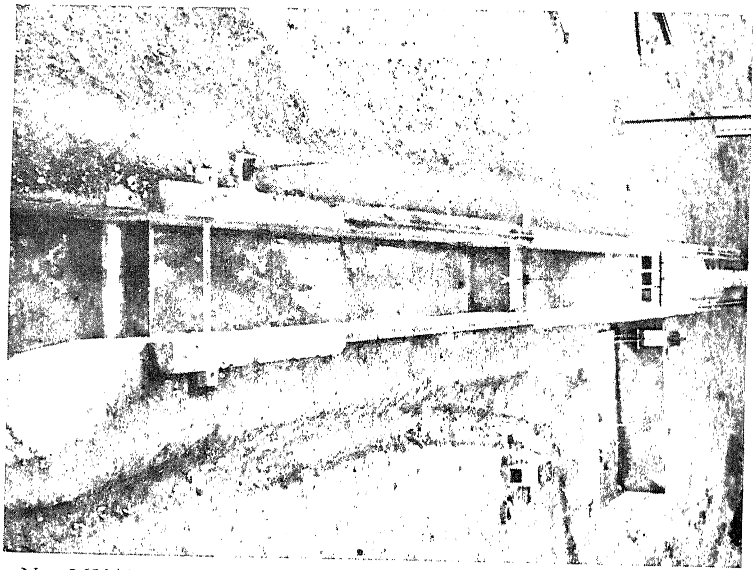

PHOTO No. 2680/55. View of the part-width geometrically similar model of the Hanumannagar barrage (Kosi River Model No. 4).

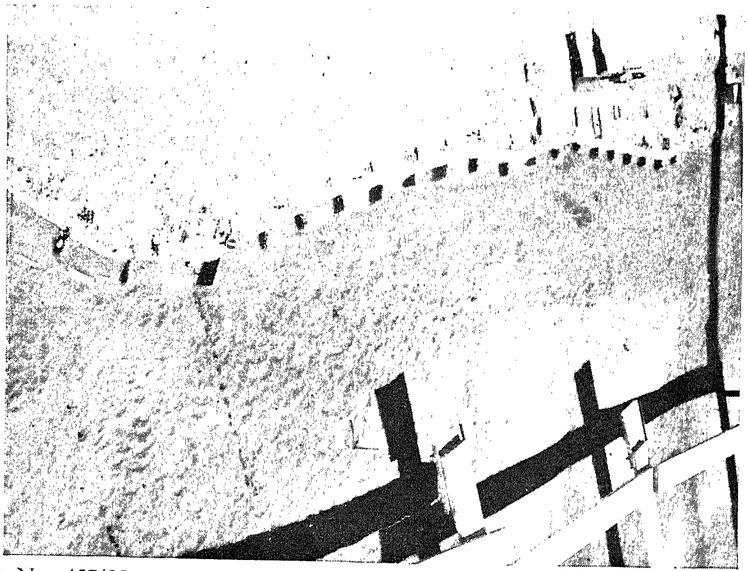

PHOTO No. 457/55. Photo of the running model showing the deflection of high velocity flow brought about by the spurs constructed at Dibrugarh on Brahmaputra River.

5. *Note on Methods of Flood Control in the Region of ECAFE*, by A. Normandin, Expert of the Bureau of Flood Control, ECAFE, UN.

6. *Flood Damage and Flood Control Activities in Asia and the Far East*, Flood Control Series No. 1, by ECAFE.

7. *Methods and Problems of Flood Control in Asia and the Far East*, Flood Control Series No. 2, by ECAFE.

8. *Proceedings of the Regional Technical Conference on Flood Control in Asia and the Far East*, Flood Control Series No. 3, by ECAFE.

9. *Flood Control*, The Engineer School Fart Beluoir, Virginia (U.S.A.), 1940.

FLOOD CONTROL IN THE DAMODAR VALLEY

By N. S. Iyengar and R. J. Prasad

(Damodar Valley Corporation, Hazaribagh)

Read at the Silver Jubilee Session of the Academy held at the University of Lucknow on December 26, 1955

The River

The River Damodar takes its origin in the hills of Chota Nagpur Plateau in the western part of South Bihar approximately at an elevation of 2,000 ft. above M.S.L. and travels a distance of about 300 miles from its source before it joins the Hooghly River, some 30 miles below Calcutta. When it has covered about 150 miles its principal tributory, the Barakar River, joins it from the north. At the confluence the elevation of the bed of the river is only 315 ft. above M.S.L.; thus the lower reaches of the river are relatively flat having an average slope of 2 ft. per mile varying from about 3 ft. per mile, near the confluence to less than 1 ft. per mile as it joins the Hooghly River. On the other hand, in the upper reaches above the confluence the average slope is more than 10 ft. per mile, it being some 30–40 ft. per mile in the headwater region.

Drainage Area

The total drainage area of the river is 8,500 sq. miles of which the area above the confluence is about 6,900 sq. miles, more than 80% of the total. The catchment above the confluence is more or less fan-shaped conducive to heavy concentration of flood flows whereas the catchment downstream of the confluence is a narrow strip with an average width of about 10 miles along the 150 miles length of the river with the result that the additional flood flows contributed by this narrow strip are comparatively of little significance.

Rainfall

The annual rainfall in the catchment varies from about 70 inches to 35 inches with an average of 50 inches. About 80–95% of the annual rainfall occurs during the period of four months, middle of June to middle of October, and most of it comes as heavy downpours during the passage of cyclonic storms from the Bay of Bengal of which some 10–15 storms reach towards this valley during the monsoon season. These storms have a duration of 3–5 days and during one such storm as much as 12 inches of rainfall averaged over the valley has been recorded with more than 25 inches in the storm centre.

Catchment Condition

The catchment is generally denuded of forests and other vegetal growth. During the long dry period of 8 month s the fields are all overgrazed and the soil exposed. Thus the heavy downpours of rain in the monsoon period find no check in eroding the soil. Heavy quantities of silt are carried in the river year after year during each flood. The catchment conditions are thus continuously deteriorating resulting in increased flood run-off coefficients and as much as 85% has been recorded.

Flood Intensities

The poor condition of the catchment, the steepness of the river courses, the fan-shape of the drainage area and the heavy downpours during a short period have all combined together most favourably to cause floods of high intensity in this river. Floods with peak flows of 650,000 cf. have been observed three times during the last fifty years and the flood of August 1913 had a volume of flow equal to 3·5 million acre-ft. in 9 days and more than 1·2 million acre-ft. on a single day.

The potential of this valley in generating severe floods can be well appreciated by a comparison and with this in view it will be interesting to note that in the river Cauvery in South India the maximum recorded flood at Krishnarajasagara (drainage area of 4,100 sq. miles) is 297,000 cf. and at Mettur (16,300 sq. miles) it is only 450,000 cf. even though most of the west and south-west parts of the catchment receive heavy rainfall as much as 200–250 inches annually.

Embankments for Flood Control

The river has been actively eroding the soil in the upper reaches and transporting it to the lower valley where it deposits the same to form its own alluvial delta. As this action progressed the river section in the lower reaches continuously decreased and the flood flows overtopping the banks became frequent. To afford protection from such floodings embankments were erected on both banks of the river, the escapes being located along the embankment on the right bank as required by the general slope and topographical conditions of the region. This gave relatively more sense of protection along the left bank than along the right bank; consequently, more valuable properties and developments grew behind the left embankment. In the meanwhile, the silting in the river-bed year after year soon reduced the river section and during floods breaches in the embankments became constant sources of danger. During the eighteenth century when a series of major floods occurred the embankment on the right bank was deliberately

breached in several places in order to protect the valuable properties along the left bank. This has resulted in the river swinging more and more in a southerly direction with Burdwan as its apex. Prior to eighteenth century the Damodar River was joining Hooghly some 39 miles upstream of Calcutta and now it joins Hooghly about 30 miles downstream of Calcutta. Of late, more and more of the discharge in the river is flowing in one of its branches called Mundeswari which joins the Rupnarain River which also joins the Hooghly lower down and the old course of the Damodar is gradually dying. Thus attempts to afford flood protections by marginal embankments have not proved successful due to such protections being short-lived on account of the continuous silting action of the river.

RESERVOIRS FOR FLOOD CONTROL

In July 1943 even a comparatively smaller flood (3,00,000 cf.) caused widespread damage throughout the lower valley. After the devastation of this flood, the question of flood control in this valley has received more thought and attention than at any time before, both by the Local and the Central Governments. As a result of the deliberations that followed the Damodar Valley Projects were envisaged and are being constructed. The scheme includes seven storage dams providing for a total storage capacity of 4·68 million acre-ft. out of which 3·57 million acre-ft. are reserved for temporary detention of floods. These reservoirs will be so operated that a design flood of peak flow of 1,000,000 cf. can be controlled to about 250,000 cf. below the confluence. Much of the silt content in the flood waters will be trapped in these reservoirs and relatively silt-free water will be released into the lower valley.

Further a systematic survey of highly eroded areas in the catchment, soil conservation measures such as construction of headwater dams, gulley plugging, contour bunding, etc., and afforestation have been taken up and some progress has already been made.

Thus the destructive action of the river will be checked almost completely and the flood protection will be more assured and lasting for a long time to come.

THE FIRST PHASE OF CONSTRUCTION

In view of the hugeness of the scheme, for the purpose of execution, it is divided into two phases. The first phase includes 4 dams providing a total storage capacity of 2·9 million acre-ft. out of which 1·32 million acre-ft. are reserved for flood control. The dams at Tilaiya and Konar are completed; the one at Maithon will be ready in 1956 and the Panchet Hill Dam

will be completed in 1957. It should be noted that Maithon and Panchet Hill Dams are most strategically situated from the point of view of flood control. On completion of the first phase, all floods of record can be controlled to less than 250,000 cf. which is the capacity of the river in the lower reaches.

CONCLUSION

Removal of fear from flood devastation by constructing these projects goes a long way in the all-round development of the region. Perennial irrigation of more than a million acres of fertile land is not a dream any more. A million ton steel plant, a huge coke oven plant and electrification of the railways are already on hand. The industrial activity around Calcutta will have unchecked scope for expansion in the direction of this potentially rich valley. The prosperity of the region in the near future will pay dividends many times the amount spent for flood control.

FLOODS AND THEIR CONTROL

By G. S. Mathauda

(Forest Research Institute, Dehra Dun)

Read at the Silver Jubilee Session of the Academy held at the University of Lucknow on December 26, 1955

Abstract

The basic causes of floods are analysed. Floods originate in the hills and their consequences are experienced in the alluvial plains. The monsoon type of climate, special geology of the Himalayas from which our problem of rivers originate and the destruction of forests in the hill catchment areas aggravate the flood problem in India.

It is shown that the traditional methods of controlling floods with the help of engineering works in the plains are based on a lack of comprehension of the true flood machanism, and sound flood control measures will have to tackle the hilly catchment areas and the plains portion simultaneously. Stress in the former will have to be on afforestation and sound soil and moisture conservation practices and in the later on engineering works like reservoirs and dykes. The lines along which work in the hilly catchment area should be done are briefly indicated.

A typical river rises in some remote hilly region in the form of a tinys treamlet which gains momentum as it rushes downhill. The increased speed enables it to carry a load of soil and stones which it picks up on the way. Other streams, big and small, join it one by one and gradually the river assumes the shape and proportions of a huge hill torrent which cuts up its banks and scours its bed and transports this eroded material along with itself. Traversing the hills the river debouches into the plains. Because of a fall in the steepness of its bed it loses speed and with that it also rapidly loses its power to carry its load of eroded material. The deposition of this material gradually raises its bed and enables it to overflow its usually low banks. The occurrence of heavy rainfall or quick release of snow water through accelerated thawing in the catchment area result in peak discharges of water in the river. This accelerates the process of erosion and deposition and serves as immediate cause of floods.

The course of a river is thus divisible into two natural parts—the hilly and the plain portions. It derives major part of its water and parctically all its load of eroded material from the hilly regions. Due to steep topography its waters are confined here to a narrow streambed for which there

is little scope for getting widened but which gets steeper every day. There is thus little flood damage in the hills. In the plains the river-bed becomes wider and shallower. This portion is further characterised by the sedimentation of the eroded material, gradual raising of the bed and frequent changes in the river's course. Its contribution to the water flowing in the river is comparatively small but it has to suffer the consequences of floods which in reality originate in the hills.

The process of erosion, sedimentation and floods has been in progress from the very beginnings of earth's history. It has resulted in the gradual wearing away of mountains and the building up of the rich alluvial plains. It has been accompanied by a certain degree of damage and loss of life and property. Undisturbed nature kept the harmful features of floods within reasonable limits. Man's misuse of the hilly catchment areas has greatly added to the severity and frequency of floods and a natural phenomenon which ought to do more good than harm has become a scourage of humanity.

The flood problem in our country is aggravated by three factors. The bulk of our rainfall is received during a short period of 3–4 months and most of it takes place in the form of heavy rainstorms. Our important river systems originate from the youngest of mountains which on account of their steep topography and unstable geology and the nature of geological formations are particularly liable to severe erosion. The forests in these hills have been mostly destroyed by the improvident action of man during the past 5–6 decades. The denuded hill slopes are overgrazed by a heavy cattle population and have been partly broken up for cultivation. No steps have been taken to effectively protect these grazing lands and hill slopes against the destructive forces of rain-water. Erosion in the mountain region has assumed serious proportions and the catchments can no longer play their full part in keeping the floods under check, which have assumed unnatural proportion.

It is hardly necessary to dilate upon the fact that undisturbed natural vegetation affords best protection to the hill slopes and thereby plays a vital role in controlling the floods. It is not a fortuitous coincidence that luxuriance of natural vegetation increases with an increase in rainfall. The quantity and complexity of natural vegetation provided by nature under any set of climatic conditions is an index to the requirements of land for protection against the natural destructive forces operating there. The role which forests play in flood control has been examined by some of the outstanding authorities in India at the 3rd Engineers' Seminar held at Srinagar earlier this year. They have clearly brought out that the multistoreyed forest vegetation maintains the water-absorbing and retaining functions of the catchment areas

at the highest pitch of efficiency and affords effective protection to the soil against erosion. Surface run-off is eliminated to a large extent and major part of the water has to travel underground before it reappears in the form of springs and enters streams. As forest growth utilises a higher proportion of the precipitation water, the total discharge from a forested watershed is less and much more regulated than the discharge from other categories of land. Erosion is reduced to its geological norm resulting in slower sedimentation of stream channels and man-made reservoirs.

As floods do great damage to life and property there are numerous instances of attempts at controlling the floods in the past. These, unfortunately, were seldom based on a clear comprehension of the fundamental causes. The relief obtained was, therefore, only temporary. A classical example is that of the Yellow River in China which, on account of its recurring floods bringing misery to millions of people through ages, has earned for itself the title of the River of Sorrow. Many of China's rulers have attempted to harness the Yellow River. The traditional way of dealing with the problem has been by building dykes, reinforcing banks and dredging the river-bed. As a result of heroic efforts some 1,100 miles of dykes line its banks in the provinces of Honan and Shantung alone. This approach has not solved the problem and devastating floods have been a recurring feature. Some 143,000 square miles of the Yellow River's catchment areas in the middle reaches are composed of fine loess, which is easily erodable. In the absence of protecting forests which were destroyed by man long ago, the moving waters carry down huge quantities of soil from this region. The sedimentation of this eroded soil in the plains raises the river-bed rapidly and leads to frequent changes of its course. The precipitated silt forms an ever thicker layer on the river-bed and much of the river is now flowing on top of the plain instead of in a channel through it. In the lower reaches the bed of the river is 10–33 ft. above the general level. It has been clearly realised now that the problem cannot be tackled successfully unless sound soil and moisture conservation practices are enforced in the upper catchment areas so that the load of silt coming down with the water is reduced to the minimum. New China has evolved a comprehensive plan for controlling the floods in Yellow River. Afforestation of the hilly catchment areas of the main river and its tributaries is an integral part of this plan. In addition there will be a series of multipurpose dams to further regulate the flow of water and to utilise these for irrigation and producing electricity. The river-bed in the alluvial plains is to be lowered by systematic dredging and made navigable for over a thousand miles.

United States of America has made great advances in the field of flood control. Through the laborious method of trial and error in connection with the floods in the Mississippi, she has clearly recognised that flood problem cannot be effectively solved unless surface flow and erosion in the upper catchment areas are reduced to the minimum. The operations in this area consisting of afforestation and other soil and moisture conservation practices are under the control of the Department of Agriculture, while those in the waterways in the plains are the responsibility of the engineers in the War Department.

A sound programme of flood control can only be drawn up on the basis of appreciation of true flood mechanism. Checking of excessive soil erosion and surface flow of rain-water in the hilly catchment area is a *sine qua non* of such a programme. This will reduce the unnatural frequency and ferocity of the phenomenon. Complete mastery would need further aids like reservoirs to store part of the flood waters for future use and dykes along its banks and dredging of the river course in the plains portion. Simultaneous action in the two natural zones of the river's course will have to be taken.

Effective treatment of the upper catchment area would need a careful survey of the area. This would determine the present extent and status of various categories of land, the human and cattle population in the area and the agricultural and pastoral habits and customs of the poeple. In many catchment areas there will be three broad categories of land, *i.e.*, forests, pastures and cultivated fields. While conducting the survey the actual condition of these three categories of land would also be noted upon.

Taking into consideration the topography, geology and climate of the region the minimum area to be kept under forest would be fixed and suitable adjustments made accordingly. Steps will next be taken to ensure that the forests are adequately protected and properly managed so as to discharge their protective functions satisfactorily. This, generally speaking, would necessitate afforestation of areas devoid of natural vegetation, elimination of fires, control over grazing and regulation of cuttings.

The other two classes of land, *viz.*, pastures and agricultural fields, would need much greater attention because the root cause of the present trouble lies here. Area for area they contribute much more heavily to the rapid surface flow of rain-water and the load of silt in the streams. Agricultural fields which are not fit for cultivation are best be reverted to forest or brought under pasture and fruit trees. Over the remaining area the practice of sound soil and moisture conservation principles such as terracing, bunding, contour

ploughing and strip cropping—should be made compulsory. Some backward hill tribes, specially in north-eastern and central parts of the country, practise what is known as shifting cultivation. This is a very wasteful practice and would have to be stopped as early as possible. The grazing grounds would be gradually rehabilitated through rotational and periodic closure, seeding of land to nutritive grasses, manuring and mositure conservation aids like trenching. Moreover, fodder species of bushes and trees would also be introduced in these areas. Scientific management of the pasture lands and agricultural fields though absolutely essential from the view-point of flood control is likely to prove an uphill task because it would involve a revolution in the agrarian economy and generations' old customs and practices of the hill people. The number of cattle kept in the hills is far beyond the supporting capacity of the available pasture land. These are let loose to find whatever sustenance they can and stall feeding is unknown. A reduction in the number of the grazing cattle would thus be necessary.

FLOODS AND THEIR CONTROL

BY S. C. PANDEYA

(*Mahakoshal Mahavidyalaya, Jabalpur*)

Read at the Silver Jubilee Session of the Academy held at the University of Lucknow on December 26, 1955

It is needless to overemphasise the importance of stopping this great havoc of floods, which is perpetually devasting agricultural land, swooping away extensive villages, killing people and cattle resulting in loss of several crores of rupees every year. Our Government appears to be quite conscious of this great problem of the present day. It is making progress with its programme of flood control with the creation of Central and State Flood Control Boards. A provision of Rs. 117·2 crores has been made in the Second Fiver-Year Plan. To its credit, the Government has also opened a Soil Conservation Centre at Kotah. The problem of flood control, however, is not a simple one but a complex of problems which are baffling the engineers of today.

ORIGIN AND CAUSES OF FLOODS

A just and objective survey of the origin and causes may reveal the measures for the flood control adequately.

Floods occur, in our country, during the monsoon season, when the rivers are over swallon. During this season the extensive catchment area of the rivers receive heavy rainfall and the run-off rushes through streams and tributaries pouring their sudden enlarged volumes of water in the main rivers. The river-beds are unable to house the sudden increased volume resulting in overflowing of the banks and flooding the countryside. This is the main cause of floods in the tropical country like ours. The swelling of rivers may be due to heavy rains on the mountains (catchment area of the rivers), sudden outbursts of clouds and even due to breaking of dams. Therefore, an appropriate clothing and increased infiltration of rain-water in the catchment area alone can minimise floods. Thus Nature can be tamed to help stop floods. Heavy rains or sudden outbursts of clouds, etc., can neither be stopped nor tamed. The rain-water in the catchment area should be obstructed. The hurdles can only be put by trees, shrubs and grasses. The natural vegetation forms humus, improves and increases the depth of soil and consequently increases infiltration. The rain-water, therefore, has to saturate the soil beneath upto several feet. This vertical travel of rain-water and ups and down of slopes will minimise the run-off to a great extent as shown in Figure 1. The infiltration of water suddenly drops down in places without

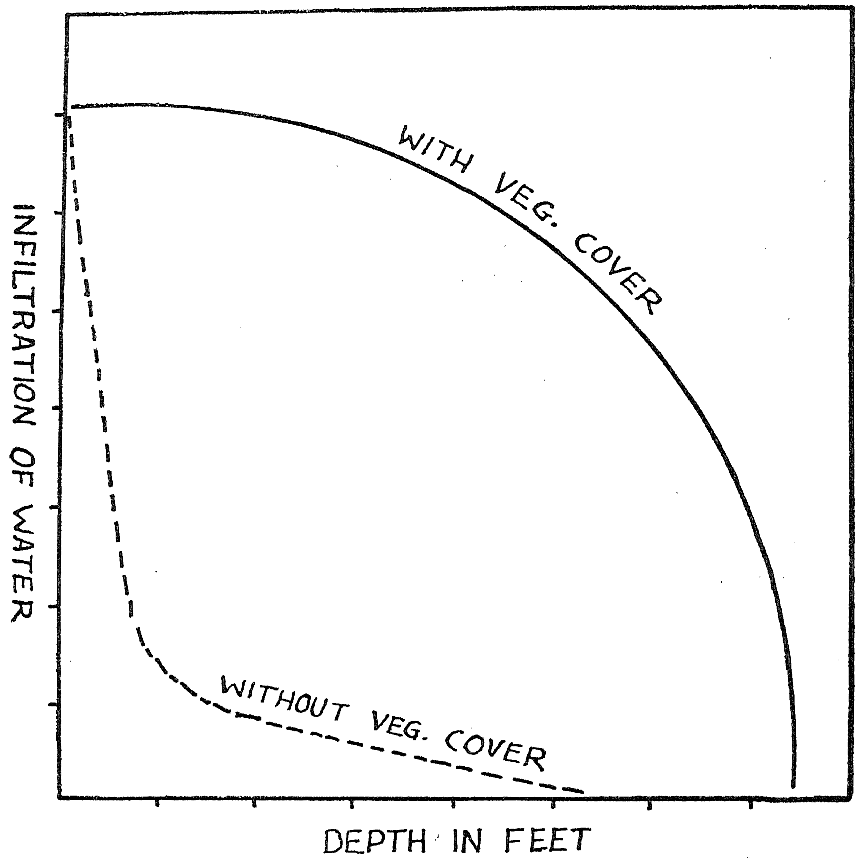

FIG. 1. Infiltration of rain-water with depth in areas with and without vegetational cover.

vegetational cover as compared to places with vegetational cover where the infiltration is gradual and to a greater depth. This can be given an experimental bias by taking 1 sq. metre of soil spread over some slopy place; pouring a bucket of water over it and by collecting and measuring the run-off water and the rundown soil. The same can be repeated with the soil covered by a piece of cloth. It will be noticed that both the run-off water and the rundown soil are greater in quantity in the previous case. This will clearly show the effects of clothing of soil in the catchment area. Thus in unclothed catchment area when it rains heavily only the superficial layer of soil is bathed and the rest drains down to river through its tributaries creating floods. Whereas, in catchment areas covered with vegetation much of the water first shall be utilised in saturating the deep vertical section of the soil, and the undulating land and only the rest will flow down. This obstruction is bound to put down the velocity of the rushing water towards the river.

The other important factor which determines the flood is the width and depth of the river-bed (its cross-section). The depth of rivers is a variable phenomenon depending upon the amount of transported soil from the catchment area. When rivers leave the hills, their velocity suddenly decreases resulting first in the deposition of stones and pebbles, secondly sand and lastly silt and clay. This deposition raises the bed of a river reducing its water-carrying capacity. The impact of this increased cusecs discharge of the rivers is undoubtedly the floods.

The origin and causes of floods may be summarised as:—

(i) Heavy rainfall and cloud outbursts in the catchment area.

(ii) Excess run-off from catchment area with unobstructed increased velocity of water.

(iii) Erosion of soil in catchment area.

(iv) Silting of river-bed.

(v) Low water-holding capacity of rivers.

Let us diagnose these five points in order to evolve measures of flood control. (i) Heavy rainfall in the catchment area, which we are unable to check. (ii) Water-holding capacity of rivers can be improved by creating dams at suitable places in rivers. However, it may be borne in mind that the construction of dams is absolutely a temporary measure. This, no doubt, lessens floods by obstructing the fast flowing water but its durability depends upon silting in the area of dams. (iii) Silting in river-beds and dams is a common phenomenon since the water ladden with soil from catchment area loses its velocity on entering the plains resulting in rapid deposition of soil in river and dam beds. It is, therefore, not surprising to hear about dams being broken. Construction of dams as the only measure of flood control shall be a simple waste of money. The water-sheds above the dams cannot be ignored. (iv) Heavy run-off of water and erosion of soil in the catchment area can be avoided with profit.

Applied Ecology in Flood Control

The foregoing brief review of the problem has shown that the solution of flood control does not lie in the hands of engineering department by construction of dams. There appears to be confusion and contradiction in the present efforts. Every department is working on its own interest. The forest department is concentrating on lumbering and burning the forest and allowing a lot to be grazed and at the same time having silvicultural practices;

the Agricultural Department is busy in clearing the fields for crops; the Government is spending millions in creation of dams and conservation of soil; the recent Van Mahotsava drives at planting trees; the Transport Department is cutting vertical sections of hills for roads without minding the landslides and rapid erosion of soil; the villagers are bent upon leaving their cattle free for grazing and so on. Such conflicting activities have given impetus to floods.

Flood control is purely a problem of applied ecology, and the purpose will only be solved if those entrusted with the work have a background and training in ecology. The science of applied ecology came into being after World War II in order to meet with the shortage of food, fodder and fuel. While studying the problems of forestry, agriculture, soil conservation, flood control, fish culture, etc., two basic concepts of ecology are mainly utilised, *viz.*, plant succession and climax and plant indicators. In the above light the whole problem can be divided on the following lines:—

(*a*) Afforestation of catchment area by trees, shrubs and grasses on the basis of plant successional studies. Contour tranching of the land.

(*b*) Proper management of lands along rivers. This will include several miles broad strip on either side of the rivers.

(*c*) If needed, then construction of dams.

AFFORESTATION

In the field of afforestation, ecology has its main application in the techniques of silviculture. In flood control the basic idea is to afforest the catchment area rather with thick vegetation. According to ecological approach this can be achieved under the following sections:—

(i) Silvicultural practices with natural regeneration.

(ii) Silvicultural practices with artificial regeneration.

(iii) Introduction of exotics.

To achieve this, first a regional and local ecological survey and classification of the forest types, climate and soil of the area has got to be undertaken.

Under the three sections described above the first includes the prescribed techniques of natural regeneration which are from applied ecology under the local management patterns and with a detailed knowledge of the local sequence of plant succession.

The development of vegetation is controlled by climate, edaphic and biotic factors. In ecology no one attempts to change the climate. Soil

conditions can be changed as a result of coaction and reaction with plants. Therefore, after growing a proper population of trees along contour tranching, the exact ecological changes are to be studied. This study is essential in order to understand the nature of acceleration or retardation of succession along a particular line. In this connection Dr. G. S. Puri, formerly at F.R.I., Dehra Dun, reports that the above techniques have helped in perpetuation of sal and silver fir communities by retarding the successional development of vegetation to communities with less important species. He further reports that the conversion of grassy areas to *Pinus longifolia* in some tracts of the Siwaliks is achieved by mere closing it for grazing. The regeneration of some *Strobilanthes balsam* type of silver fir forests has been claimed by grazing. Fire helps the regeneration of *Pinus longifolia* and inhibits those of silver fir and spruce. In raising artificial plantations of a number of species the vegetation is clear-felled, debris burnt, and ashes scattered before replanting the area. The present state of most of the sal forests is considered to be due to fire conservancy, giving sal an advantage over other species.

In the second section is included artificial propagation of plants. Apart from the aforesaid technique, a proper species is to be chosen which has a high soil-binding capacity. Autecological studies are useful in evaluating the species. This will give the exact type of species best suited under the existing complex of climate, soil and biotic factors. Root system in terms of erosion control has to be given importance. Further, culture experiments are essential to confirm the behaviour of species.

Under the last section, on the basis of aforesaid autecological studies, exotic species are to be selected depending upon the exact evaluation of the complex of ecological factors. Attention is to be paid to the factors which influence the germination of seeds, growth and development of exotic species. Therefore it is necessary to know the phytoclimate of the region in terms of microclimate. A study of coaction and reaction shall be the master factor here.

A similar study is needed for shrubs and grasses. As for grasses it may be mentioned here that grasses have a high erosion control value. Species must be selected which have a high ecological amplitude with respect to shade tolerance in addition to the aforesaid ecological factors.

LAND MANAGEMENT

It is essential to have a proper management of land, miles broad, along rivers after they have left the catchment area. Grasses, apart from afforestation, can be grown in these areas. Grasses can be sorted upon successional

studies. A climax community is the final product under the existing environmental complex but inbetween are several seral stages which may be of greater value. In a climax community only those species exist which are quite endeavouring. Seral stages are mobile stages and are uprooted when put under competition. In every region at least three climaxes can be recognised, *viz.*, edaphic showing the primary succession, biotic and climatic communities. Under the edaphic climax the development progresses in which stability of soil is the main factor. In Sagar (M.P.) the climax community is represented by *Themeda caudata* and *Iseilema anthephoroides*. The bioclimax community includes *Bothriochloa pertusa* and *Dichanthium annulatum*, growing on stabilised soil. The former community is also the climax community under the existing climate. It is only the result of grazing that it gets transformed into biotic community, and the further growth remains arrested. A detailed study of the secondary succession in the grasslands of Sagar has revealed that firstly, there is an overall increase in the existing species. After this, the grasses higher in rank increase in coverage over the low phase species due to competition; and lastly, when the coverage is mainly by the climax species. Thus, with a clear background of succession and with a little manipulation useful grasses can be grown in any area.

If required then for artificial growing of grasses seeds can be spread by aeroplane just before the onset of monsoon.

Slope bunding of river banks is another important factor in land management.

Dams can be constructed purely for the purpose of irrigation or for hydroelectric schemes. After proper management of catchment area, silting of dams will become a very long process.

At the end I may say that a share of flood control measures may be entrusted to "Indian Council of Ecological Research" which is specialising in Soil Science, Agronomy and Soil Conservation besides foresters and ecologists.

PROPER LAND USE FOR REDUCING FLOOD CRESTS

By S. P. S. Teotia

(Soil Conservation Department, Damodar Valley Corporation, Hazaribagh)

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Flood control begins where the rain falls and run-off starts and ends only when that run-off has safely reached the ocean. Run-off and erosion are greatly affected by the management of land. Improper land use in the headwaters areas causes increased soil erosion and run-off causing the siltation of stream channels and reservoirs downstream resulting in floods affecting the productive bottom lands. The problem of floods does not end with the construction of flood control dams on the major rivers. A co-ordinated approach to the problem includes the control of headwaters by treating the land in the entire catchment or upstream area to obtain the maximum of infiltration consistent with the proper land use. Cropping practices that give the maximum of plant cover depending on the climate and physiographic conditions and economic needs of an area are the most effective ones for reducing flood flows. No single treatment can be expected to provide the maximum possible protection to the entire catchment, and various other measures are needed for control of erosion and reduction of sedimentation load of rivers to supplement the effectiveness of major flood control structures downstream.

There is only one way to retard run-off and stop erosion and maintain land in a permanently productive condition and that way is to treat every acre of land in a catchment according to its needs and capabilities. One of the first tasks, therefore, in any upstream programme for flood control should include Land Capability Classification to provide a sound basis for Soil and Water Conservation by assigning each area to the use to which it is best adopted and recommending measures for control of erosion and improvement of land use.

Conservation farming and using land according to its capabilities in the headwaters areas, where lies the key point of all water management, plays an important part in reducing flood peaks. The choice of measures and the effectiveness of land use practices for catchment treatment in reducing run-off is influenced by topography of land, degree of erosion, soil type, frequency,

interval and duration of rain storms, weather sequence preceding a rain storm and length of growing season.

In some catchments physical conditions may be such that flood damage can be reduced by increasing infiltration of rainfall into the soil, by adopting improved land use practices, like strip cropping, using sod forming grasses for improving structure and thereby increasing water-absorbing capacity of soil, water spreading, terracing with bench or level types to retain water behind terraces, contour cultivation for retaining water in the furrows, utilization of crop residues for mulching.

Control of gullies and eroded areas by various biological and mechanical measures. The latter areas may be converted into grassed waterways, pastures, or forest, sanctuaries for wild life, or converted into paddy fields or conservation ponds according to suitability which will substantially decrease the flood flows either by holding back sufficient rain-water or by regulating flow of excess water. Whereas in other catchments, where soils are shallow, steep or impervious and conditions for water absorption are not favourable, use of additional run-off retarding measures and surface storage measures are required to protect the land from erosion and bring about a valuable improvement in water management. The latter may include the adoption of graded channel terraces for safe disposal of water at non-erosive velocity, diversion channels, retirement of steep erodible land from cultivation to permanent cover of pasture or forest and proper management and grazing control, which will help in storing much of rainfall which would otherwise run-off into streams to increase flood crests. Proper land use combined with effective water disposal system through stabilized waterways, construction of surface detention dams at critical points and other run-off retarding measures like chutes, drop inlets, stone and masonry check dams will to a great extent reduce flood peaks by holding back excess flood waters, and reduce siltation of big reservoirs designed for flood control.

It is true meteorological forces involved in rainfall cannot be altered significantly, but run-off is to a large extent dependent on management of land. Careless and indiscriminate erosion of land inevitably causes accelerated soil erosion and increased run-off with the consequent flood damage. Proper management of land and use of proper water conservation and land use practices, will definitely retard and reduce run-off by increasing infiltration.

There are two types of storms that cause floods. The thunderstorm rains of short duration and high intensity falling over small areas cause flash floods, which are inevitable on small slopy catchments. The stagnant cold front storms caused by moist maritime air flowing over a cold continental air mass,

are characterised by long duration, low intensity, spread over wide areas, contribute greater run-off causing floods. The latter type of floods can usually be predicted in time and can be controlled by providing adequate soil and water conservation measures on the land.

This is true that floods are never likely to be eliminated, and this is also true that we can increase the flood hazard by the way we use our land. Land use practices have limited application in reducing flood crests particularly in case of flash floods over small slopy catchments. Gentle floods, of course, are a boon in enriching the soil with rich fine silt and clay deposited every 3–4 years without actually affecting growing crops. There are other areas where coarse sands are deposited to a great depth and flood water stands to a great height for a considerable length of time. The nature, extent and frequency of floods are so different from place to place that no general recommendation for proper land use can be given without a thorough study of factors involved, *viz.*, frequency, intensity, duration, time of occurrence, and physical effects on soils and crops.

I feel that soil and water conservation practices extended within catchment areas of the major rivers will make a substantial contribution towards flood reduction.

A NOTE FOR THE SYMPOSIUM ON FLOOD CONTROL

By S. P. Chatterjee

(Department of Geography, University of Calcutta, Calcutta)

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A perusal of the leading geographical journals of India and other countries of the world reveals that geographers like engineers and other scientists are vitally interested in the study of flood problems, though their method of approach is somewhat different. They are in favour of making a thorough study of the flood plains as human habitat with a view to assessing not only the flood losses but also gains in terms of increased fertility of land and potential water resources for irrigation and power generation.

It is perhaps true that the frequency and magnitude of floods have considerably increased in India in recent years, causing enormous losses in the densely populated parts of Bihar, West Bengal, Assam, Orissa and Madras. These losses could have been minimised had there been planned encroachment on the flood plains of the rivers passing through those areas.

Micro-Relief

In a low-lying tract like the Ganges Plain the spreading of flood waters is conditioned by micro-relief. Take for instance the areas which were heavily flooded in the Uttar Pradesh in 1954. The wet low-lying tract of Terai, extending little south of the Rapti, and portions of the Gogra alluvial tract were heavily flooded, but the area in between these two (the upartiar tract), which was slightly higher, escaped flood damage. A detailed contouring of the flood plains of India is, therefore, necessary to delineate zones which are subject to floods. The types of occupancy in the different parts of a flood plain can then be so adjusted that the losses during the future floods would be the minimum.

Topographical Changes

Floods in the Himalayas are often caused by landslides which block the courses of rivers to form temporary lakes. The water-level in such lakes gradually rises and eventually the river overflows and undermines the natural dams, causing devastating floods in the lower reaches. A flood of this kind had occurred in the Garhwal Himalayas, when large blocks of limestones, weighing some 800 million tons, crashed down into the valley of a tributary

of the Alakananda and blocked the valley completely for some time. The dam was eventually smashed by the force of water, which rushed down the valley, flooding the countryside and even damaging the head-waters of the upper Ganges canal at Hardwar.

A careful record of slopes subject to landslides and other forms of mass movement of rocks is therefore to be maintained, and temporary lakes, when formed, are to be artificially drained so as to avoid the danger of overflooding in some future date.

Earthquakes are also responsible for topographical changes, which accentuate flood danger. North Bihar and the Brahmaputra valley of Assam are near the epicentres of some of the devastating earthquakes and suffered heavily in the past. River-beds were uplifted, which obstructed natural drainage, and tectonic depressions along the river courses were formed, which at the slightest rise of water-level get submerged. The depressions along the Burhi Gandak are the typical examples.

Floods may be caused when a river captures the head-water of another river. This is a very common phenomenon in all watershed zones. In Central India the watershed zone of the head-waters of the Mahanadi, the Narmada and Wain Ganga presents many examples of river capture. It is also quite possible that the Manjira which now flows into the Godavari was a tributary of the Krishna in the past.

Not only the discharge of the victorious river increases appreciably the flood discharge, but the water-table of the area through which it flows with the captured river is also raised, making the area more liable to floods.

The shifting of a river from its original channel to that of a neighbouring canal may give rise to floods. The Saki River in the Gaya District can be cited as an example. This river changed its course during the closing years of the last century and flooded extensive fertile fields in the Nawada subdivision, converting these fields to a sandy waste.

MAN'S INTERFERENCE WITH DRAINAGE CHANNELS

It is not uncommon to find that due to man's unplanned interference with drainage channels, many a flood plain suffers from overflooding. The Ghaggar River for example, which rises on the lower slopes of the Punjab Himalaya, has in the upper reach its waters diverted for irrigating lands of every village through which it passes with the result that the river fails to maintain its channel free from the load it carries and gradually dies out. In the absence of a clear-cut channel the excess of water in a year of relatively high rainfall easily overtops the low banks of the river and floods the adjoin-

ing region. This accounts for the floods that visited the Punjab along this and the neighbouring valleys of the Patiala and Markanda.

Man's interference to existing irrigation channels might also contribute to overflooding. The Banganga River, for example, which joins the Jumna, south of Agra, used to flood heavily the plains of Bharatpur and Agra during the period the irrigation works connected with this river remained unrepaired.

A thorough study of the major topographical features including drainage channels is imperative before we can solve our flood problems. Mere constructions of dams, barrages and encatchments might halt this menace for some time, but we must take a long-range view in solving this problem and point out what adjustments in the flood plain occupancy are needed to make full use of our flood waters. Let us hope that when all our multipurpose river valley development schemes are completed, our agricultural land will not be subject to destructive floods.

Let us now briefly refer to areas in Northern India which suffered most during the recent floods.

NORTHERN INDIA

Flood problem in Northern India is most acute. This part of India is most densely populated and has extensive flood plains built up by the three biggest river systems of India—the Indus, the Ganges and the Brahmaputra. It is true that only a portion of the Indus plain now lies in India, but the head-waters of Indus and its five important tributaries—the Jhelum, Chenab, Ravi, Beas and Sutlej are in the Indian territory.

From the point of view of the geographical study of the flood plains of Northern India, the vast alluvial tract extending from the Punjab to Assam can be divided into five major provinces and twelve sections.

Major Provinces		Major Sections
I. Punjab Plains	..	1. The Ravi Plain.
		2. The Beas-Sutlej Plain.
		3. The Patiala-Ghaggar-Markanda Plains.
II. Ganges Plains	..	4. Middle Ganges Plain.
		5. Lower Ganges Plain.
III. Ganges Delta	..	6. Northern Section.
		7. Southern Section.

Major Provinces		Major Sections
IV. West Bengal Plains	..	8. The Damodar Plain.
		9. The Ajay Plain.
		10. The Mayurakshi Plain.
V. Brahmaputra Plains	..	11. The Upper Brahmaputra Plain.
		12. The Middle Brahmaputra Plain.

I. The Punjab Plains

1. *The Ravi Plain.*—Compared to other rivers of the Punjab the Ravi has a much smaller catchment area. Moreover, a substantial part of its water is drawn off from near the points the river enters the plain to feed the Bāri Doab Canal. These factors reduced flood intensity. But in years of excessive rainfall, which might exceed 100 inches in the catchment area near Dalhousie, moderate floods do occur in the Ravi, which cause lateral erosion of its banks. In 1954 large area was inundated below Dera Nanak. This town also suffered from floods in the past, when a famous Sikh shrine was washed away.

2. *The Beas-Sutlej Plain.*—The tract lying immediately south of the upper Siwalik sub-montane tract in the Jullundur and Hoshiarpur Districts was heavily flooded in 1954. This tract is intersected by innumerable sand filled channels, which remain dry through the greater part of the year, and fail to carry excess of rain-water falling on the hilly portion. The waters of the Beas and Sutlej also had overflowed their left banks at the time of 1954 floods.

3. *The Patiala-Ghaggar-Markanda Plains.*—Further south in the Pepsu State flood waters rushed through the dry beds of the Patiala, Ghaggar and Markanda, flooding both the banks of these rivers.

II. Ganges Plain

Of the major regions subject to catastropic floods the Ganges Plain deserves first mention. The flood waters have ribbon-like pattern following the courses of the Jumna and the Ganges, and along the Himalayan tributaries coming from the north like the Gogra in the west, the Gandak in the middle and the Kosi in the east.

4. *Middle Ganges Plain, Uttar Pradesh.*—In Uttar Pradesh the land subject to high floods mainly occur along the courses of the Gogra and its two principal tributaries, the Sarda (the Chauka) and the Rapti. Basti and Gorakpur Districts suffered most by the last flood. Of the rivers flowing

through the Uttar Pradesh the Gogra is the most unstable one. It continually erodes its banks and deposits its load on the flooded areas. A number of embankments have been constructed in the past by local inhabitants, but none of them could withstand the rush of flood waters in years of abnormally high rainfall. Unlike the nothern tributaries the parent stream, the Ganges, is less liable to floods. So also is the Jumna, which flooded only small areas last year near Delhi, Muttra, Hamirpur and Allahabad.

5. *Lower Ganges Plain, Bihar.*—The Ganges from near its confluence with the Gogra and the Son to the northern foot of the Rajmahal hills flows through the State of Bihar. The Ganges overflows its banks in this reach, and hence at places embankments were constructed to protect villages and standing crops. The combined flood waters of the Ganges and the Gogra, however, innundate large tract in the southern part of the Saran District.

No other flood plains of India suffered so much from recent floods as those of North Bihar. Some part or the other of North Bihar gets heavily flooded every year, and it has been estimated that some 200 crores of rupees worth of crops and houses were destroyed during the floods of 1951 to 1954. The worst sufferers were the farmers of the Kosi flood plain. The Kosi, as is well known, has been continuously changing its course through its rich fertile and densely populated alluvial cone for the last 200 years, and by depositing large masses of sand and medium size silt, laid waste in its westward march some 3,000 sq. miles of good arable land. Not only the further encroachment of arable land by the river has to be stopped but the arable land, that was devastated in the past, has also to be reclaimed.

III. Ganges Delta

6, 7. *Northern and Southern Section.*—The combined waters of the Ganges and the Brahmaputra have built up the Ganges Delta which, in its lower portion, is intersected by innumerable tidal channels. This delta covers an area of about 50,000 sq. miles both in West and East Bengal, and is very densely populated and intensively cultivated. The upper reaches of most of the distributaries of the Ganges have been silted up, giving rise to extensive floods every year. The premature use of the flood plains in the Ganges Delta is considered to be one of the main causes of destructive floods in this area. The Bhagirathi is the westernmost distributary of the Ganges. From the dry weather flow of this river, it is evident that it is dying in its upper reach. The drainage problem in the Ganges Delta has to be solved first by the resuscitating the tributaries of the Ganges. Further encroachment of the southern face of the Delta for human occupancy has also to be stopped.

IV. The West Bengal Plains

8, 9, 10. *The Damodar, Ajay and Mayurakshi Plains.*—The rivers flowing to the west of the Bhagirathi—the Damodar, the Ajay and the Mayurakshi are entirely rain-fed, having their sources in the Chota Nagpur plateau. These rivers remain almost dry for nine months in the year from October to June and have torrential flow during the remaining three months, the maximum discharge in the rainy season being five to eight times greater than the annual average discharge.

Of this group of rivers, the Damodar is the largest, and its harnessing for irrigation and generation of electricity is almost complete. I got an opportunity to investigate the catastropic floods of the Damodar in 1943. The breach of the main marginal embankment on the left bank of the river near Manikhati in that year caused the flood waters to rush northward through its former channels, specially the Behula. The rate of the flow of water was found to be over 16 miles per hour at certain places. I had then suggested that as a temporary measure part of the annual flood waters of the Damodar should be allowed to escape through its old channels, thus rendering its old flood plains again fertile and minimising flood danger in the lower courses of the river.

V. The Brahmaputra Plains

11, 12. *The Upper and Middle Brahmaputra Plains.*—The Brahmaputra floods have done considerable damage to the towns and villages which stand on its banks. This river carries more water than any other river in India, its maximum flood discharge being 2 million cusecs, but the channel being sand-filled, is not deep enough to carry this enormous volume of water. The floods normally commence in May with the thawing of snow in Tibet and Eastern Himalaya, and then they are acentuated by the monsoonal rains pouring incessantly from June to September. The rise of level of water in parent stream prevents waters from the tributary streams to enter into the main river. This contributes to the rise in the water-level of the tributary streams causing widespread floods and giving rise to marshy areas near the confluences of the Brahmaputra with its tributaries. The frequency and magnitude of the Brahmaputra floods are partly due to deforestation in hills, bordering the principal head-waters of the Brahmaputra—The Dihang, the Dibang and the Luhit.

FLOOD CONTROL

BY C. L. DHAWAN

(Irrigation and Power Research Institute, Amritsar)

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OVER any region liable to floods, the rainfall, its intensity and frequency are the most important factors for studying the causes and nature of the floods. Floods due to landslides or blocking of the stream by glaciers or reservoir failures are rare. But an unexpected landslide occurred in September, 1893 in the upper reaches of Ganges and 800 ft. above the river-bed, a length of about 2 miles was completely filled with rock and earth. The breach took place on August 25, 1894, causing heavy floods.

The contributary factors may be listed below:

(*i*) Heavy rainfall in the catchment area with the rapid run-off.

(*ii*) Heavy melting of snow.

(*iii*) Silting up of the stream by the detritus.

Being in the monsoon belt, practically, the whole of India except the south eastern part receives the bulk of its rainfall from June to September. The monsoon wind enters Bengal and Assam from the Bay of Bengal and gets deflected by the Eastern Himalayas and follows south-easterly to easterly direction. This brings rain over the Gangetic Valley, Punjab and Rajasthan in summer. It is very rare that the floods are witnessed in this region, especially in the Punjab in October.

The question naturally arises "Can we predict the floods from the forecast of heavy rains?" It is an accepted fact that a quantitative estimation of rainfall, which will occur under any synoptic situation, is not possible in the present state of meteorological studies, though from the study of synoptic charts, we may forecast the possibility of the heavy rainfall in a particular region some 36 to 48 hours ahead. But the synoptic analysis can only be carried out correctly in a particular area, provided the actual rainfall observations from that area are known. The main difficulty that stands in the way of forecasting reliably heavy rainfall warning and consequently floods is due to the lack of meteorological observations especially from the Upper Himalyan region. Secondly for anticipating correctly the intensity of floods, it is very essential to know the correlation between the rainfall and

the floods in the catchments of the rivers concerned in the form of regression equation for a long period.

When rainfall occurs, part of it soaks into the soils and is known as infiltration, part of it is evaporated—and the rest either remains upon the ground or runs off to the stream channels immediately. That portion of the rainfall, which remains on the ground, is called the "Surface Pondage" and that which runs off immediately over the surface to the stream channel is termed "Surface run-off" to distinguish it from infiltration which, too, reaches the stream channel as run-off through the soil.

Since the surface run-off moves faster than the run-off through the soil, the peak flood discharges will vary directly with surface run-off rates and a high infiltration capacity will mean more steady stream flow.

Roessel[13] is of the opinion that immediate increase in the river flow following a rainy spell is not always entirely due to "Surface run-off". His analysis lead to the fact that the true ground discharge may form a major part of the flood flows. He is firmly of the view that changes in the ground water elevations through infiltration have an immediate effect on the discharge at nearby points. Therefore the surface run-off alone may not be responsible for flood peaks and sensitiveness of discharge to rains.

The other school of thought believes that water taken into the soil is of no consequence to run-off. But it is also observed that rainfalls occurring at different stages of the monsoon (pre-monsoon, during monsoon and post-monsoon) though similar in other characteristics like intensity, frequency and duration produce varying amounts of run-off. Therefore it is very obligatory that run-off ratios, *i.e.*, the ratio between the vloume of rainfall and the volume of discharge from a catchment attributable to the rainfall, should be investigated thoroughly for different valley watersheds for all seasons, before we can assess correctly the true behaviour of floods in a particular region and to see how far the two schools of thought discussed above affect the nature of floods in relation to the rainfall in that area. The drawing of the rainfall graph and the resulting hydrograph will tell clearly the relation between rainfall and floods with time. Though Horton[9] states that peak flood discharges will vary directly with surface run-off rates, yet we cannot ignore Roessel's (*loc. cit.*) contention that the infiltration rate of a soil has its effect on the flood discharge. The question of soil moisture and the underground water-table can in no way be ruled out. To be more precise, as the rainy season advances, the requirement of water for satisfying field moisture capacity becomes less and a shorter time is needed to satisfy-it. Therefore for the rainy spells of the same intensity the ground water

outflow starts earlier and consequently contributes greatly to the flood period outflow as compared with the period, when the soil moisture deficiency has increased. This takes a longer period for satisfying the field moisture capacity level. It means that a greater volume of moisture is required for saturating the soil and the contribution of the infiltration to the " flood period " run-off is decreased.

It has already been stated that the correlation between the rainfall and run-off for different seasons is very essential before we are in a position to predict the intensity *cum* duration of a flood. The longer the period of the correlation, the more correct is the prediction. The main factors to be studied in this respect are the following:

(*a*) Rainfall, their frequency and duration, covering practically the whole of catchment area.

(*b*) Data of other climatic elements apart from rainfall.

(*c*) Watershed characteristics, including the topography, physico-chemical properties of the soil, vegetative growth.

RUN-OFF FORMULÆ

Many empirical formulas have been proposed for the determination of run-off. A few of them are given below:

1. Khosla's formula.

Khosla's formulæ for run-off are very simple in application and make the monthly and annual run-off depend solely on the rainfall and average temperature in the catchment. The formulæ are:

$$\mathrm{R} = \mathrm{P} - x\mathrm{T} \quad \text{(For annual run-off)}$$

$$\mathrm{R}m = \mathrm{P}m - \frac{\mathrm{T}m - 32}{9 \cdot 5} \quad \text{(For monthly run-off)}$$

R, P and T are the annual run-off, precipitation and average temperature in the catchment, while Rm, Pm and Tm are their monthly values.

2. Bremner:

$$q = \frac{3{,}000}{3 + 2\sqrt{\mathrm{M}}}\,.$$

3. Codley:

$$q = 200 + \sqrt[3]{\frac{1}{\mathrm{M}}}\,.$$

4. Fanning:

$$q = 200 \sqrt[6]{\frac{1}{M}}.$$

5. Fuller[2]:

$$q = q\,(\text{average annual})\ (1 + 0{\cdot}8 \log T).$$

6. Harman[8]:

$$q = \frac{30{,}000}{M + 200} + 15.$$

7. Kuichling[11]:

(*a*) $q = \dfrac{1{,}27{,}000}{M + 370} + 7{\cdot}4$ (rare floods)

(*b*) $q = \dfrac{44{,}000}{M + 170} + 20$ (occasional floods).

8. Metcalf and Eddy:

$$q = \frac{440}{M^{0\cdot 27}}$$

9. Murphy:

$$q = \frac{46{,}790}{M + 320} + 15$$

where

q = Maximum flood discharge in cubic feet per second per square mile.

M = Drainage area in square miles.

T = Number of years in period considered.

C = Coefficient varying with stream.

The revised run-off formula of Pettis[12] is:

$$Q = C\,(PW)^{1\cdot 25}$$

where

Q = Crest discharge of probable 100 years flood in cubic feet per second.

C = A coefficient that varies in different sections principally in accordance with humidity to some extent with topography.

W = average width of drainage area in miles.

This may be obtained by dividing the drainage area in square miles by the length of the river alone at the point where the discharge is needed.

This formula is designed for one frequency only, that of once in 100 years, and its use is also limited to areas between 100 and 40,000 square miles.

A glance at the above formulæ shows that though we have been studying the flood problem in India for a pretty long time, yet there is lack of regular scientific data at our command from which we may predict the occurrence of a flood in a region. Therefore it is very necessary that Scientific Institutes in different States should immediately take up this problem in right earnestness and examine in detail the utility of the above formulæ with special reference to the limitations needed, if any in forecasting the floods in the respective regions. This needs immediate consideration, as more difficulty has arisen from the misuse of the formulæ than from their use.

An important method of studying flood flows is afforded by the flood hydrograph. A discharge-rating curve is applied to the record of gauge heights from which a continuous curve of time discharge is obtained. This curve is influenced by the different factors, affecting the regimen of the river above the station. Therefore a series of flood hydrographs at different stations along a river furnishes a real basis for the anticipation of the floods in that area.

Another important problem in flood control studies consists in the study of the effect of proposed reservoir storage system upon the shape of the flood hydrographs at different points on the river below the reservoir systems and the corresponding effect of these systems in reducing flood peaks. The flood hydrograph of the different stations on the main river and the tributaries go a long way in the determination of the above effect. The essential basis for such investigations is, therefore, to draw a sufficient number of flood hydrographs in order to find out the effect upon the main river and tributaries.

The application of the statistical method of analysis to hydrological investigations was suggested by Allen Hazen.[4,5] His method is based on a theory of sampling. The period of run-off record is divided into equal units of time and the unit of time is generally taken as the year, as the year is the only interval of time in which the flood opportunity is the same. The flood values are arranged in order of descending magnitude and plotted on a probability paper with flood magnitudes as ordinates and percentage of

time or probability of occurrence as abscissas. A curve is drawn through the plotted points. The curves can then be plotted for a short distance beyond the range of the observed data and the flood magnitudes that may be expected in periods of 50 and 100 years may be gauged. In Hazen's book on "Flood Flows,"[5] detailed information is given on the application of the probability method for the determination of the magnitude and frequency of floods.

Summing up the above discussion, we come to the conclusion that the factors which affect the magnitude of design flood peak are many. But in most of the cases the data available are only the year in which the highest flood has occurred in the past and the intensity of such a flood. It may be assumed that the maximum flood in the past represents, to a great extent, the combined effect of the topography of the catchment and the meteorological elements, producing a heavy flood, such as the occurrence of high storm preceded by saturation of soil. This representation will be more accurate, the longer the record. On this basis the design flood peak may be determined. Statistical relations have been fitted between the length of record and percentage addition made to obtain the design flood peak by Dhir. The following are the relations for the different rivers of India.

(*a*) *North and Central Indian Rivers.*

$$P = 46 \cdot 19 - 0 \cdot 348\ N$$

(*b*) *South Indian Rivers.*

$$P = 47 \cdot 78 - 0 \cdot 398\ N$$

where P is the percentage addition to be made to the maximum flood value to arrive at the design flood and N is the period in years, for which that flood has been the maximum. The above relations have been slightly modified as follows:

(*a*) *North and Central Indian Rivers.*

$$P = 50 - 0 \cdot 40\ N$$

(*b*) *South Indian Rivers.*

$$P = 50 - 0 \cdot 45\ N$$

N is not to be less than 25·30 years.

The above formulæ need to be verified thoroughly for the different rivers in order to investigate their limits of application.

Finally in those cases where no discharge observations or gauged data are available, it is possible to get the information of a peak flood mark reached

in the past by personal enquiries from local population. On the basis of these marks and knowing the cross-section and the slope of the river, the maximum flood discharge can be worked out. Knowing this value and the period N for which this has been the maximum flood figure, it is easy to determine a fairly approximate value of the design flood peak. But for collecting all these data scientifically, it is very necessary that a regular wing should be attached to the Scientific Institutes of the different States, who should be made to carry out all types of research in this direction.

FLOOD CONTROL MEASURES

The main flood protection measures are discussed below seriatim:

(*i*) Channel and Drainage Improvement.

(*ii*) Construction of Levees.

(*iii*) Building of Reservoirs.

(*iv*) Soil Conservation Measures.

(*i*) *Channel and Drainage Improvement:*

(*a*) *Channel Improvement.*—The real object of channel improvement is to increase the discharge or carrying capacity of the stream. This can be accomplished in two ways:

(*i*) By increasing the velocity.

(*ii*) By increasing the size or cross-section of the stream.

INCREASE IN VELOCITY

The velocity of flowing water is affected by the hydraulic radius, slope of the water surface and the roughness of the channel. The different formulæ used for measuring the velocity of flow are given below:

1. Kutter's Formula.

$$V = \frac{41\cdot6 + \frac{1\cdot811}{n} + \frac{0\cdot00281}{s}}{1 + \left(41\cdot6 + \frac{0\cdot00281}{s}\right)\frac{n}{\sqrt{r}}} \sqrt{rs}$$

2. Manning's Formula:

$$V = \frac{1\cdot486}{n} \cdot r^{2/3} \cdot s^{1/2}.$$

3. Bazin's Formula,

$$V = \frac{87}{0\cdot552 + \frac{m}{\sqrt{r}}} \sqrt{rs}.$$

4. Biel's Formula:

$$V = \frac{1{,}811rs}{0{\cdot}0663 + \frac{f}{\sqrt{r}} + \frac{8{\cdot}2t}{(100f + 2)\,V\sqrt{r}}}$$

5. Barnes' Formula:

$$V = 58 \cdot 4r^{0{\cdot}694} \cdot s^{0{\cdot}496}.$$

6. William's Formula:

$$V = c_1 \cdot r^{0{\cdot}67} \cdot s^{0{\cdot}54}.$$

7. Elliot's Formula,

$$V = \sqrt{1{\cdot}5rh},$$

where

V = mean velocity in feet per second,

s = slope,

r = hydraulic radius,

n = a coefficient depending upon all the characteristics of a channel, which produce retardation of flow.

m in Bazin's formula is the roughness coefficient, which varies from 0·06, as applied to very smooth surfaces to 1·75 for earth channels.

h in Elliott's formula is fall of the surface in feet per mile.

The generally accepted formulæ for measuring the velocity of flow are those of Kutter, Manning and Bazin.

For increasing the velocity of flow either hydraulic radius or the slope or removing fallen trees and clearing the banks is to be carried out. Sometimes cut-off are also provided. The hydraulic radius can be increased by deepening the channel or increasing its width or the height of the banks. The adequate solution depends upon the merits of each case. It may be mentioned that the channel improvement, as the only means of flood protection, is applicable only to small streams, as we can increase the channel cross-section only to a limited extent.

Drainage Improvement

Drainage is the removal of water from soil. If the drainage in a certain region is good, there is no possibility of the accumulation of water. This means that the flow of water will not be obstructed and consequently the damage to the property, cattle, etc., etc., will be considerably minimised.

Therefore it is very important to design the drainage system in such a way that it meets all the requirements of the region.

The oldest method of drainage is the open drain. The principal data needed for designing the drainage system in certain locality are the following:

(*i*) Boundaries of the watershed.

(*ii*) Proximity of the river or hill torrent, existing canals, distributaries, water-courses, etc., etc.

(*iii*) Possible outlets for drainage system.

(*iv*) Bridges, their location, size and condition.

(*v*) Highways and Railroads.

(*vi*) Villages and isolated buildings if any.

(*vii*) Areas under cultivation.

(*viii*) Forests.

(*ix*) Swamps.

(*x*) Relative elevations of all parts of the watershed.

(*xi*) Variation of the nature of soil.

(*xii*) Rainfall, temperature, humidity records, etc.

The dimension of the cahnnels are determined in such a way that the whole area is drained satisfactorily. An additional depth of 1 foot or more should be provided to take care of the silting.

Regarding slope of the banks, it should not be determined arbitrarily and without proper investigations. If the soil is sandy or sandy-loam, slopes of 2 on 1 or even 3 on 1 may have to be used. Sandy soils usually need higher slopes than clayey ones from the stability point of view.

The maximum discharge for which a drain is designed is determined from Kutter's, Manning's or Blazen's formula used for the flow in open channels. But the real conditions which should be fulfilled by a drain are the following:

1. The drain should be capable of carrying the necessary discharge.

2. The velocity of the flow should be such as neither to produce scouring nor silting.

3. The bottom of the drain must be sufficiently low to drain even the waterlogged areas nearby.

4. The side slopes should be such that the banks remain perfectly stable.

CONSTRUCTION OF LEVEES

Levees are continuous earth-dams, which are high enough to serve as artificial banks during flood periods and can with stand a maximum flood. The term " dike " is synonymous with levees. Levees are the oldest known form of flood protection.

The effect of confining the flood waters of a river between levees is as follows:

(*i*) Velocity of flow and hydraulic slope are increased. This increases the scouring action through the leveed portion.

(*ii*) Flood wave passes through the leveed portion quickly and thus increases flood peaks downstream.

(*iii*) It decreases the surface slope of the stream above the leveed portion.

The first problem which requires attention in the design of a levee system is the probable maximum flood discharge, which the leveed stream has to carry with particular reference to time period.

Construction of embankments for flood protection has been opposed by some engineers and scientists for the following reasons:

(*a*) The tendency of alluvial rivers to build their beds and valley lands to even higher levels.

(*b*) The inevitable disasters that accompany the rise of flood levels in such rivers owing to the restriction by bunds of their natural flow and overflow.

(*c*) The vulnerability of bunds and their heavy maintenance costs.

(*d*) Their impermanence and heavy recurring costs in the construction of successive alignments to replace damaged ones.

The embankments have been used for flood protection in Italy, United States, Viet-Nam, China, Burma, Germany, etc., etc. The results of the behaviour of the embankments for a very long time in these countries will be of immense help to us in knowing the limitation, if any, of the construction of the levees for the flood protection works.

The observations of the engineers of some of the countries are discussed below:

The main results of Mackintosh's on Irrawaddy River (Burma) are as follows:—

(*a*) The low water-levels at Hanzada, during the period from 1931–35, are on an average lower by 0·085 metres than the low water-levels for the period from 1876–80.

(*b*) If a comparison is made of the level, of the medium waters at Prome, 160 kilometres below Hanzada, where the bed is very stable and Hanzada it can be noted that the water-levels at Prome and at Hanzada exactly correspond during the period 1883–1935.

(*c*) The capacity factors were calculated for the same sections below Hanzada in 1875 and 1933. They show that the river had a better carrying capacity in 1933 than 1875.

The observations made by French engineers on the Loire and by German engineers on the embanked Rhine have shown no raising of the bed and no tendency to such raising.

Major S. A. Ockerson made the following statement at the Dayton Congress of the American Society of Civil Engineers (1922): " Extensive research has established that no raising of the river-bed results from the building of the dikes. On the contrary, the last comparisons show that there is a well marked tendency towards a large cross-section, which includes a deepening of the bed."

Professor P. C. Mahalanobis in his book *Rainfall and Floods in Orissa* made a very detailed study of the variations between 1868 and 1929, in the level of the Mahanadi at Naraj, at the origin of the delta of this great river and he arrived at the following conclusion (page 172):—" In fact it is found that the average variation in level is of *plus* 0·001 feet per year, *i.e.*, a little more than an inch per century, which is negligible from both the statistical and the physical point of view."

Fantoli, who studied the observations of P_0 from 1807–1907, was also of the opinion that there was no rising of the bed.[1]

Taking all the points into consideration and depending upon the evidence of the engineers of different countries, who have had long experience of dikes, it is concluded that the construction of earthen embankments are the cheapest to build and the cheapest to maintain till future research on the behaviour of rivers within the defined embankments show otherwise.

Recently embankments were constructed on both sides of a very treacherous and mighty hill torrent (Nasrala choe in the Punjab), which has been responsible for great devastation in the past. They have rendered good service in protecting Hoshiarpur City even in the present unprecedented floods of October 1955 in spite of a few breaches in the bunds.

Embankments are also being constructed as a means of flood protection works for Kosi river in Bihar.

Building of Reservoir

Reservoirs may also be built for the purpose of flood control, where conditions make this economically desirable. In this case, flood waters are held back temporarily to prevent or minimise the danger of floods in the river below.

The chief obstacle to the construction of reservoirs for flood protection alone is the cost.

There are two kinds of reservoirs, the storage reservoirs, and the detention reservoirs. The best example of the use of detention reservoirs for flood protection relates to Miami Conservancey District in Ohio (U.S.A.). Bhakra Dam, one of the highest dams of the world, is being built in the Punjab. A few other reservoirs, *i.e.*, Tung-Bhadra, Hirakud (Orissa), Damodar Valley, etc., etc., are also being constructed not only for the single purpose of flood control but for the multipurpose object of providing power, navigation and irrigation facilities.

Soil Conservation Measures

The relationship between forests and floods has several aspects, which can with advantage be considered under the following headings:

(*a*) Influence of forests on rainfall.

(*b*) Influence of forests on loss of moisture by evaporation and transpiration.

(*c*) Influence of forests on run-off and seepage water.

(*d*) Influence of forests on soil erosion and the raising of stream bed down below.

Observations show that forests probably do not appreciably influence to incidence of summer rainfall in our country. It does not need even a moment's reflection that the loss of water from the soil through evaporation is much higher on bare land than a land covered with vegetation or forests.

The surface run-off is a destructive agent. A few years back experiments were conducted in Kangra Valley by the Punjab Irrigation Research Institute. The summary of the results are discussed below:

(*i*) When the rainfall is very small, say 0·10 inch or below, the run-off depends upon the initial moisture content of the soil.

(*ii*) The percentage of run-off depends more on the intensity of rain than on the total quantity, the highest percentage being at a time when the intensity is also maximum.

(*iii*) When the vegetation cover is well established it reduces the amount of erosion and consequently the removal of vegetation leads to a considerable increase in erosion.

(*iv*) About half the water is received as rainfall by a bare surface run-off and does not soak into the soil.

(*v*) About $\frac{1}{8}$th of the water received by grass covered land runs off its surface, while for land covered with grass and scrub the proportion is only 1/10th.

(*vi*) Trays with similar cover-grass, or grass and scrub or no cover behave within limits in a similar manner.

(*vii*) The different quarters of the year do not markedly affect the percentage of run-off.

(*viii*) There is gradual increase (leaving the last quarter out when there is little rain) in the proportionate run-off from the bare trays. In the first six months the run-off was about 40% of the water received, in the next six months it was nearly 50% and in the next quarter it jumped to 60%. The covered trays showed no such changes.

(*ix*) The bare trays lose soil on an average at about 10 times (and sometimes more than 10 times) the rate at which grass or grass and scrub-covered trays lose it. The latter two types of cover do not appear to be unlike between themselves.

(*x*) The greatest loss of soil is in the monsoon months whatever be the type of cover.

A glance at the above results show that soil conservation measures are very essential for the protection of floods. Every region has its own problems to be investigated before we can finally decide about the type of vegetation needed in that area for the flood protection works. Therefore it is very desirable that immediate research should be carried out both in the laboratory, semi-field and field scale in different localities.

A word about the different types of erosion will not be out of place. There are three types of erosion, which require to be combated:

1. Gully erosion.
2. Sheet erosion.
3. Wind erosion.

Remedial Measures

The remedial measures may be classified under two headings:

(*a*) Preventive.

(*b*) Curative.

Preventive Measures

(*a*) *Land use surveys.*—Rational use of land is a measure that is very greatly needed in our country. To ensure proper distribution, a proper land use survey is essential and land should be classified according to its ability to bear the different crops. A balance must be found between forests, pasture and agriculture.

(*b*) *Grazing regime.*—The present indiscriminate grazing must be stopped. Rotational closures may be introduced in areas where grazing is heavy in order to improve the quality of the grass and also to save the land from denudation.

(*c*) *Proper forest management.*—A great deal of educative propaganda is needed to save the trees from damage.

Curative Measures

(*a*) *Gully plugging.*—This consists in constructing a ring-bund round the ravined land and then constructing brush-wood or earth bunds in the ravines for holding the water and deposit of silt. A system of spillway for the free movement of water from these bunds is essential to avoid breaches. The upstream sides of these plugs are then planted up with trees or grasses to further stabilise the soil and to prevent it from erosion.

(*b*) *Contour trenching.*—This is carried out in badly eroded areas in sloping country. The area is contour surveyed and 6 inches to 1 foot depth trenches are dug along the contour to hold up the rain-water. Plantation of trees or grass species is done along the berms of these trenches.

(*c*) *Strip cropping.*—This is done on areas, where there has been a considerable amount of sheet erosion. In the initial stages the strips are planted with a field crop and a leguminous crop alternately. The strips are interchanged in the next cropping season. This process is continued till the area has been completely reclaimed, and a deep subsoil formed.

(*d*) *Closures.*—Sometimes when the erosion is not much advanced a simple closure of an area against grazing and other rights of user has a very beneficial effect.

The last but the most important question is that of establishing regional research stations to investigate easy but suitable methods of flood control

in the different regions. The following are the localities where one or more research stations are immediately required:—

1. Desert soils.
2. Alluvial soils.
3. Black soils.
4. Red soils.
5. Lateritic soils.

The importance of research into watershed problems in our country cannot be overemphasised. The pattern of rainfall, the nature of vegetation and agricultural *cum* pastoral practices in our country differ materially from the conditions in Europe and America. It is, therefore, very essential to collect reliable information for our own conditions. We must possess full and accurate facts regarding the different aspects of this knotty problem, if we have to deal it in a scientific manner. It is imperative that we make an immediate start at the earliest possible date, as effective mastery over floods would demand a proper co-ordination between the watershed and water-ways features of the flood control programme, which can be only chalked out after proper scientific investigations.

SUMMARY

The following salient points are brought out from the above study:

1. The major causes of floods are :
   (*a*) Intense rainfall over small catchments.
   (*b*) Heavy precipitation of several days durations over large watersheds.
   (*c*) Landslides on blocking of the stream by glaciers.
   (*d*) Reservoir failures.

2. Being in the monsoon belt, practically the whole of India except the south-esterly part receives the bulk of its rainfall from June to September. Therefore usually the floods are experienced in these months.

3. The main difficulty, which stand in the way of forecasting heavy rainfall warning and consequently floods, is due to the lack of meteorological observations from the Upper Himalyan Region. Secondly, for anticipating correctly the intensity of floods, it is very necessary to know the correlation between the rainfall and the floods in the catchments of the rivers concerned in the form of regression equation for a long period.

4. The main factors to be studied in evaluating the relation between rainfall and the forecast of floods are the following:

(*a*) Rainfall, their frequency and duration covering practically the whole of catchment area along with detailed data of other climatic elements.

(*b*) Watershed charactertics including the topography, drainage conditions, physico-chemical properties of the soil and vegetative growth, etc., etc.

5. The different formulae proposed by the various workers for the determination of run-off need to be tested for the individual streams and catchments in order to examine the limits of their applicability for our conditions.

6. Flood hydrography studies should be taken up immediately in the respective regions.

7. There are two general classifications of all flood control measures. In the first class are those projects which hasten the flow of the water from the watershed. This relates to channel *cum* drainage improvement and levee construction. In the second class are those projects which retard the flow of flood water by storage or detention reservoirs, and soil conservation measures.

8. For grappling rightly the problem of flood control in our country, it is very urgent that the different regional institutes should be asked to take up this problem on the above lines. They should first examine the causes of flood control in their respective areas and then investigate the methods of combating floods.

9. The soil conservation investigations merit immediate attention of the soil workers in India. Both laboratory *cum* semi-field and field experiments should be started taking into consideration the physico-chemical properties of soil, the slope of the land, rainfall characteristics, etc., etc.

10. A sub-committee of soil scientists should be formed, who should chalk out the programme of soil conservation in India. They should meet at least two times a year and discuss the problems being confronted by them and the progress made by them. Government of India may be approached for funds.

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FLOODS AND THEIR CONTROL

By H. L. Uppal

(Irrigation and Power Research Institute, Amritsar)

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Introduction

When a river swells beyond its normal snow melt flow it is said to be in flood. There are several flood stages, low, medium, high and exceptionally high. In the low and medium flood stages, the swollen river water may still be contained between the banks and though the discharge may be high yet it does not cause any anxiety. In the high and the very high flood stages, however, the river water spills over the banks and inundates the valley land causing damage to land, crops, property, cattle and human lives, etc. Generally the term flood which is defined as an overflow from the river or any other body of water is associated with this stage. This flood stage is the source of anxiety and danger to the people settled in the river basin. The greater the depth of flow taking place over the banks, the larger is the damage caused by it. Again the larger the river, the greater is the valley land and bigger the population in the valley and heavier the damage. From times immemorial water has been considered as a great blessing. The old proverb says " where there is water there is God". No wonder then that important towns were founded and great civilisation developed along the river banks. Civilisations which flourished on the rivers also suffered heavily by the river when in high floods. The blessing of being in the vicinity of a river turns into a curse, very often, when the devastating floods are experienced in the rivers and bring untold miseries to people.

Causes of Floods

The floods may be caused by excessive rainfall melting snow, bursting of reservoir dams or temporary ice or glacier obstructions in the stream. Generally high floods are caused by the heavy storm rainfall in the monsoon season. The period of the occurrence of cloud burst is very important. If a heavy rainfall occurs in the beginning of the monsoon season, the floods produced by it may not be very high as a lot of the precipitation goes into the dry ground in wetting it. If the same intensity of rainfall occurs towards the end of the monsoon season when the ground is wet, it produces a very high flood. Generally high floods are experienced towards the end of the monsoon period, *i.e.*, in September or October.

Very high floods of 1928, 1929, 1947 occurred in September. The unprecedented floods experienced in Punjab rivers in 1955 occurred in October. These floods were preceded by a heavy cloud burst. The cloud burst sometimes is so heavy that more than half of the year's precipitation occurs in a few hours. If the maximum storm rainfall continues over a longer period, high floods of great duration occur. When a heavy precipitation continues to occur beyond a certain period the inhabitants of the areas do get a misgiving of the occurrence of the high floods. In the valley of Kashmir if the rainfall continues on for more than 36 to 40 hours the people living in the Jhelum river basin pack up their belongings and either shift to the second storey of their houses or migrate to higher places in order to protect themselves against the expected floods.

Another cause of the floods is the heavy sediment load which the rivers bring. When the rainfall is heavy a large amount of sediment is washed down from the catchment areas into the stream. The head waters on account of steep slopes carry on the load to the plains where the slope being flat the material starts depositing. More and more sedimentary material gets deposited and the bed rises. With the rise in the bed, the river stage rises and water which used to be contained between the river banks before, now overflows them and inundates the valley land. As the top water which is comparatively clear spills over the bank the remaining discharge in the river has to transport all the sediment load which before the spills was being carried by whole of the river discharge. The part discharge in the river cannot carry all the sediment load which starts depositing on the bed and the bed further rises. The raised bed causes floods even in comparatively lower river stages. The frequency of floods thus increases.

FUNCTION OF FLOODS

1. *Building up of valleys.*—Rivers form their own valleys. The sedimentary material brought by the river from the upper and the lower catchment are deposited in the plains at the foot-hills and lower down. In floods the volume of water that comes down in the river is much more than can be contained between its bank. The water spills over the banks and floods the land. Along with the spill water sedimentary material is also brought which deposits itself on the bank and on the land. Each flood, therefore, builds up the land on the sides of the river with the sedimentary material brought by it. The process of building up the valley by the river is very

interesting and at the same time complicated. The river does not follow a straight course. It adopts a serious course and meanders. It has a certain width known Khadar land or meander belt in which it moves about. This is the limit of its maximum swing from one end to the other. Similarly the length of one consecutive loop is a meander length and the width from one curved bend to the other is meander width. When the river has built up at one place it shifts its course and starts afresh the process of building up at the other place.

The convex loop changes into concave loop and the areas which had no opportunity of receiving flood spills before get the spill water with the new course. Flood spills generally occur at the concave bend of the rivers. After the concave bend has been at a certain place for a certain period and spill has been occurring and the land buildings going on the meander moves downstream and the concave bend goes towards the other side. The same process of spilling over the banks and land buildings with the sediment brought by it starts. Some times after the loops have developed to the full extent and a large ratio between the loop and the cord has been established the river makes a cut-off along the cord during one of the floods. When the river has raised its bed and flow takes place over the ridge formed by itself, it breaks through to low-lying land and starts over again the process of silting up. All these processes continue on to build up the valley land.

2. *Supplying manurial silt.*—Flood spills upto a certain magnitude are a boon to the farmers, because of the manurial value of the silt which the spill water leaves behind on the land. A bumper crop is obtanied after such floodings. Expensive artificial manures which otherwise will be essential can be avoided if the land is subjected to flooding by the silted water occasionally. Similarly, large depressions in the land are filled up by the sediment-laden flood water.

3. *Flushing of river-beds.*—Floods have a great power of flushing the river-bed. In comparative low river discharges the river bed begins to rise and if a big flood does not come for a number of years the rise in the bed becomes appreciable. Large shoals form here and there in the river. One big flood, however, washes these away and the river-bed comes to the original level again.

Magnitude and Frequency of Floods in Recent Years

A general impression exists in the people that the floods occur much more frequently now thanin the past. Also that the magnitude of the

flood experienced in recent years is far greater than that in the past. Every new flood excels the record of the previous floods.

In order to investigate this point the flood data for the last 30 to 40 years for certain rivers were examined. Besides this the observations made elsewhere regarding this behaviour were also studied. In the Punjab very accurate river discharge data exist. In no other State of India such regular discharge observations over a long period are available. The river discharge data available since 1922 regarding four Punjab rivers, *i.e.*, Ravi, Sutlej and Yamuna were statistically examined. The year's peak flood was taken in each case. Important results obtained in each case are discussed briefly.

River Ravi at Madhopur.—Before 1947, floods higher than 2,67,000 cs. were unknown in Ravi river. A high flood discharge was considered to be in the neighbourhood of 150,000 cs. and this was the highest which was experienced in Ravi in normal years. Occasionally a flood higher than this would occur. The highest recorded flood discharge was 2,67,000 cs. After 1946 in less than a decade floods 200–250 per cent. higher than the highest previously recorded were experienced. Regarding the frequency of a flood of this magnitude it has occurred practically every third or fourth year. It may be considered from the study that in the recent past floods of much greater magnitude and much more frequency have occurred in Ravi river.

The peak discharges considered in this case were for the period 1922 to 1955. The following observations are made after classifying the period into two equal halves, *viz.*, 1922 to 1938 and 1939 to 1955.

(i) For the entire period 1922 to 1955, the peak discharge varies from 39,900 cusecs to 6,17,000 cs.

(ii) In the period 1922 to 1938, the peak discharge exceeded 1 lakh cs. 4 times; whereas in the period 1939 to 1955, the peak discharge exceeded 1 lakh figure 8 times.

(iii) In the period 1922 to 1938, the peak discharge in any year never exceeded 2 lakh cs. while in the later half, the figure of 2 lakh cs. has been exceeded 4 times. It is obvious, therefore, from the above division that:

(*a*) There is a great variation in the peak discharge values from year to year.

(*b*) The floods in the recent years have been of increased intensity.

Regression line fitted to the peak discharges of river Ravi has a positive slope which shows that the peak discharges are on the increase during the recent years.

Sutlej river above Ferozepur Headworks.—The data considered as before covered the period 1930 to 1955. Dividing the period into two equal halves, *viz.*, 1930 to 1942 and 1943 to 1955, the following points are noticed.

(i) During the first half, the peak discharge figure exceeded 2 lakh cs. in 7 years whereas in the later half, the figure was exceeded 12 times.

(ii) In the first half, the peak discharge exceeded 2 lakh cs. in case of one year whereas in the later half, this figure was ecxeeded 7 times.

Jamna river above Tajewala Headworks.—The data of peak discharges considered covers the period 1930 to 1955.

Dividing the period into two equal halves, following points were noted:

1. Peak discharges in the first half exceeded 1 lakh cs. in 4 years whereas in the later half, the figure of 1 lakh cs. was exceeded 12 times.
2. Peak discharges in the first half exceeded 2 lakh cs. in 3 years, whereas in the later half, the peak discharges exceeded this limit 4 times.
3. The maximum ever-recorded discharge, *viz.*, 5,63,000 cs. also falls in the later half.

The regression line fitted to the peak discharges during the period under study has a positive slope as usual.

The following conclusions are drawn:

(*i*) In case of this river too, the floods have been of increased intensity.

(*ii*) The trend of the peak discharges is also towards increase.

Summarising it may be said that in the Punjab the floods which have been experienced during the last about 10 years are much bigger and have occurred much more frequently than those ever experienced in the past. The highest peak recorded before 1946 has been exceeded several times during the last 10 years and the new peaks are two to two and a half times as big as the old ones.

Flood Damages

In Punjab, the land of five rivers, the floods in the real sense as it is understood in Assam, Bihar or Bengal were not known. Occasionally an inundation occurred of the valley land which was accompanied with some damages of land, crops or property.

In recent years the damages caused are colossal. Huge devastation has occurred. Especially in the year 1955, a complete deluge of Punjab has taken place. The losses sustained are far in excess of those that have occurred in flood States like Bihar or Assam.

MAN'S ENCROACHMENT ON RIVER'S JURISDICTION

By putting up inhabitation, founding towns and constructing large buildings and houses on the river banks and in the region of the meander belt the man has seriously encroached upon the river. The activities of the river are thus restricted. The river is a very sensitive organism. It reacts to the interference in its jurisdiction by man very vehemently. The river during floods tend to destroy or wash away the structure and other obstructions put up in its way by man.

BATTLE BETWEEN RIVER AND MAN

Since anything constructed in the meander belt upsets the river regime, the river tries to undo what man does there. A battle starts between the river forces and the forces of man. Man ingeniously devises measures to protect his interests and to keep off the river. The river brings bigger and bigger floods to submerge the valley and this causes damage. Human efforts have, therefore, been directed from very early times to control the floods in the river. A brief discussion of the various measures adopted is given here.

FLOOD CONTROL MEASURES

Bund, Embankment or Levee

The first and the oldest measure adopted to obtain protection against the floods is the construction of a bund! The land-holder settled on the river side constructed his own bund to protect his river front. Thus grew more or less a continuous line of bunds. As it was the result of individual or group efforts the bunds had several bends and sharp curves, each man kept his own interest foremost to save on the land by constructing the bund on the river edge. The specification for different reaches were different, the over-all alignment defective and the design inadequate and unsatisfactory. Even gaps were left in the bunds. Such bunds afforded little protection against high floods and were invariably washed away. The responsibility of flood protection works later on was taken over by the Government, in most of the countries and proper bunds were then constructed. The embankment system to protect the valley land against overflow by flood is very antique. Every important river in the world which is subject to overflow has been provided with bunds, embankments or levees. The Nile

river was embanked about 4,000 years ago. Similarly Euphrates and Tigris rivers from very early times have been confined between levee lines. Important embankment system exists along the Rhone, the Danube, the Vistuhila, the Rhine, the Po, the Arno, the Volga in Europe and in the Middle East. The Yellow river in China was embanked with high levee lines centuries ago. In the U.S.A. the elaborate levee system on Lower Mississippe is more than a century old.

Indus, Ganges, Gandak and other rivers in the Indo-Gangetic Plain are confined between huge bunds on both sides. Similarly, Godawari, Mahanadi river in the South and in the East are also confined by bunds. In India embankments on several other rivers have been constructed recently after the occurrence of recent heavy floods. A heavy programme of building embankments on important rivers in practically all the different States has been prepared for execution in the next five years.

The levee methods of flood control is purely of a defensive nature. The levees are erected mostly on the land outside of the area of the river. At certain places the levees on either side of the river are placed close together and at other places far apart. When the levees are attacked by the river flow they are set back or retired. If the levees are constructed very far apart and the meandering stream is confined within the embankments then there is no danger to the levees. In most cases, however, the embankments are situated close to the banks in the region of the meander belt. Large breaches in high bund have occurred at several places on the Euphrates river near Habbanyana. Similarly the bunds on the Jhelum river in Kashmir give away at several places during flood. In such cases when the river meanders move downstream they attack one or the other levee causing heavy damage by breaching the levee. Therefore, besides constructing the levee system for flood control the river must also be trained along a particular course so that no damage occurs to the levees due to the vagaries of the river. The training of the river in flood control and flood protection measures may be a subsidiary method but is equally important as the levee system itself.

Design of Bunds.—The most important point regarding the bunds is its alignment. The earthen bunds never offer any serious destruction to the erosion. The alignment should be such that the bund must be out of the direct attack of the river. It should never be constructed on the river edge. At curve points specially the bunds should be placed on a sufficiently retired position. The Regional Technical Conference on Flood Control of 1951 ECAFE laid great emphasis on the location of bunds. At all curves

the bunds should be pitched and provided with stone aprons of sufficient length and depth.

Dimensions of Bunds.—For large streams the following dimensions of the embankment are proposed:

Top width	20 feet.
Free Board over the maximum flood discharge	5 feet.
Slope on the water face	$2\frac{1}{2}$–1.
Slope on the back side	3–1.

With terraces to cover a minimum hydraulic gradient of 1 in 7 by a minimum of 1·5 feet.

The dimensions of the bunds are largely controlled by the nature of the earth available. They are constructed in layers preferably not more than one foot thick, watered and consolidated. The embankment on the back side is extended to contain the hydraulic gradient at the maximum river discharge. Depending upon the nature of the soil, a minimum hydraulic gradient of 1 in 6 should be adopted. Terraces 1·5 feet at the minimum are provided to cover this gradient. The river-side face should be kept as flat as possible, not steeper than $1\frac{1}{2}$: 1 in the first instance. Otherwise, sloughing would occur. Since the bunds on most of the rivers do not come into use every year but only once in a few years these are liable to be neglected. Rat holes in the bunds lead in several cases to a serious disaster. In most of the important levee lines a lorry road is run on the top or the top is metalled or concreted so that the levee is kept in proper order. The Mississippi, the Po and the Rhine have all metalled tops over which regular traffic takes place. Similarly heavy embankments, levees or dykes have been constructed in Holland on the coast in order to prevent the overflow from the sea during high tides. The dykes are very large and carry a wide road with three to four lanes on the top.

Maintanance of bunds or embankments.—A careful and continuous maintenance of the embankments will be required. A bund, which is closely watched and carefully maintained, withstands the floods; otherwise, it is seriously threatened and often fails. The bunds, therefore, must be properly supervised and maintained. This is the first essential required by these bunds. Before the approach of the flood season a programme of supervision and emergency plan should be carefully drawn and brought into operation as soon as the water reaches a certain level. Wide resources

in personnel and equipment should be made available to the organisation entrusted with the work of bund supervision and flood control.

Since millions of people live under the protection of embankment or levees it is imperative that levees should be strong and carefully maintained so that no breach occurs in them during any river stage. People live under a sense of complete security in the presence of the levees and move about their normal duty even during high floods. In the event of breaches or washing away of the levees heavy damages occur. The magnitude of disaster depends upon the height of levee, the flood discharge and the nature of populated area behind the levee. The losses from the breaching of the levees are much greater than those which would occur from the same flow if levee did not exist. In the latter case the onrush of flood overflow is not so sudden and concentrated and the people are cautious and prepared for that.

Functioning of the embankments.—The bunds confine the river flow between the banks. Since spilling is prevented the river level rises in the presence of the embankments. Higher and higher flood stages are experienced in the embanked river. The levees are strengthened and raised from time to time. In the presence of the levees in position the damage which is caused by the flood spill is prevented. However, the land which in the absence of bunds received the supply of fertile silt from the flood spills is now deprived of it. The process of raising of banks and the building of the valley by the river from spills is stopped with the confinement of the river by bunds. The flood peak rises and the duration of the peak decreases in the confined river.

Influence of embankments on the river beds. Does the construction of embankment raise the river bed?—In the past a lot of controversy has raged on this point, whether the bunds on the river banks raise the bed of the river or not. The theory that the construction of embankments raised the bed of the river was started in France by de-Prony after his inspection of the Po river in floods. The embankments on the Yellow river in China were also held responsible for raising the bed of the river. To investigate this point an examination of the Rhine river was made by Hague. The observations taken in Cologne from 1846 to 1849 and in Dusseldorf in 1800 to 1879 show a rise of about 0·6 to 0·7 foot in one century on the assumption that the minimum flow did not change.

The Mississippi River Commission after examination of the reach of the Mississippi river where embankment was developed to the highest

degree, came to the conclusion that the bunds do not raise the bed of the river. Ockerson from a comparison of surveys of the river at different periods concluded that no raising of the river-bed on account of building of levees was observed. Townsend in 1912 came to the conclusion that there was no sign of silting up of the bed on account of the dykes. On the other hand, dykes smoothened away irregularities and made the flow uniform. Hathway in 1951 stated that the bed of the Mississippi river showed signs of lowering.

In Italy, the behaviour of the Po river is an interesting example regarding the effect of dykes and levees on the bed of the river. The first series of the study of this problem was made by Lambardini. To him, observations extending roughly over several centuries did not show any indication about the rising of the river-bed. Fantoli calculated the average of a yearly maximum, mean and minimum height in the Pontelagoscuro river for a successive period of ten years for a century from 1807 to 1906. The net result of his laborious calculations backed up by observations was that no modification of the bed, either raising or deepening, was in evidence in any section of the Pontelagoscuro river. Shah also, from a study of ninety years record of the Mahanadi river, did not find any rise in the bed of the river.

Do bunds or embankments alone give necessary protection against floods ? The behaviour of embankment on Mississippi river.—The behaviour of bunds on important rivers such as Mississippi in U.S.A., Ganges in India, Jhelum in Kashmir, India, Euphrates in Iraq, Yellow in China and also the sea flood dykes in Holland has been examined in order to assess correctly the value of the bunds.

On the lower Mississippi the bunds are very old and a regular record of the effect of each big flood has been properly kept. The Mississippi river has been confined between high levees from very early times. The Mississippi River Commission soon after its formation in 1879 took the work on the levees on a very extensive scale and very earnestly. This was based on the assumption that a confined alluvial river will enlarge its own channel to such an extent as to pass flood discharge of any magnitude safely between the levees. The river would widen and deepen fast enough to take care of increasing flood discharge. Following this policy the Commission adopted a plan to close all the outlets, lakes and swamps and bunds on the sides of the Mississippi river. Levees were built higher and higher and the standards of grade and cross-section were raised. As each subsequent flood surpassed the previous record flood the ultimate levels of the high flood waters could not be accurately arrived at and therefore, the

permanent levee grade and cross-section could not be announced by the Mississippi River Commission. The levees constructed were already over 20 to 25 ft. high. For a safe river these had to be further raised and extended at the bases. The floods of 1882, 1912 and 1922 caused serious damages to the levee systems and resulting in heavy duration. Mississippi River Commission backed by the active co-operation of the Army Corps of Engineers followed " Confinement System or Levees only". This was the declared policy of the State and also of the Commission since its inception. The earlier investigation by Elliot laid great stress on levees or bunds. The delta survey report of Humphery and Abbot advocated ' Levees only ' after considering the different methods of cutting off bends, diversion of tributaries and detention of reservoirs. In 1874 the Levee Commission also advocated levees as the sole measure for protection against floods. The Mississippi River Commission in 1880 again advocated proper design of levees only for confining the river in the main channel. The Nelson Report of 1898 also recommended a complete system of levees on Mississippi river from Cairo (Illinois) to the head of the passes in the mountains. The President of the Mississippi River Commission on 11th June 1926 in reply to an enquiry on that subject again confirmed the Commission's " policy of levees only ".

The public of the State of Louisiana and in particular of the New Orlean City seeing that every subsequent flood surpassed the previous one in bringing out heavy devastation, loss of life and property, criticised vehemently the policy of the Mississippi River Commission of ' Levees only ' or ' Confined Rivers'. They protested against the closure of the creeks and spill channels and organised agitation against the Commission policy. In a report of Safe River Committee Association of Commerce Building on " What to do to prevent devastating floods in the Ohio and Mississippi River and on the Lower Missippissi Valley and Insure Flood Protection to the City of New Orleans and make the State of Louisiana Flood Proof for ever " the Mississippi River Commission and the Corps of Engineers was badly criticised for their action of confining the rivers and demanded explanation for the wrong done to the country by their policy. These people alleged that levees could not carry the big flood safely and that spillway and by-pass channels such as the Cypress Creek Spillway and the Atcha Falya Outlet or Red River Basin Spillway at Old River must not be closed. A strong countrywide protest was made by these people against the Mississippi River Commission.

In support of their demand for not confining the river between the levees the Committee quoted the experience of India which was against the

levees. A letter from the Secretary to the Government of Bengal in the Irrigation Department, Calcutta, dated May 5, 1925, No. 18871, was reproduced under the heading "Failure of Levee System in India, Embankment being abandoned".

In 1925, a plan based on lower flood levels by using Spillway for escapage for flood control between Arkansas in the valley of Mississippi river was submitted by Kamper to the Safe River Committee of 100.

In spite of the agitation by the people against the levees, the Mississippi River Commission and the Army Corps of Engineers stick to the policy of 'Levees only' and 'protection of the levees by bank revetment' as a measure for flood control and protection.

Also mostly as a result of unsuccessful artificial cut-off at Tarrapin neck above Vicksburg and Palmyra below Vicksburg, the Commission followed a policy of "No cut-off at any cost". No other flood control measure excepting 'levees only' was adopted in spite of the fact that the Congress in 1911 approved of the plans of the California Debris Commission to control floods on the Sacramento and Sanjoagir rivers which departed from the policy of the 'levees only' provided floodways as well as levees.

The floods of 1927 unprecedented in the history of the Mississippi river followed by consequent heavy destruction shook the belief of the Mississippi River Commission in the policy of levees only and compelled the United States Engineers to consider the measures to deal with the problem of flood control. The Mississippi River Commission in 1928 after giving a thorough trial to the levees came to the conclusion that levees alone were inadequate for flood control problems and other measures such as floodways, channel improvement should also be adopted.

INDIA'S EXPERIENCE OF BUNDS' CONSTRUCTION

India's experience of bunds has also been not very happy. An extract from a letter from the Secretary to the Government of Bengal in the Irrigation Department, Calcutta, dated May 5, 1925, No. 1887 I, is reproduced below:—

> "In the plains the country is partially protected with embankments —the outcome of a system introduced about 70 years ago, when an attempt was made to give full protection by this means. The outcome has been that the river-beds have been raised, the embankments breach severally when there is more than a normal flood and the position has become more acute as time progressed. Where possible embankment

are now being abandoned; there are many cases in which the land outside them is several feet higher than within them with the result that the so-called protected areas have now become relatively low and drainage has become inefficient.

The closing off of the normal spill has led to the deterioration of the health of the people and it has been established without doubt that where a river can spill, the health of the people is much better than in the tracts in which spill is cut off. Where possible, therefore, the guiding principle at the present day is to increase the area over which the rivers spill by the introduction of silt-laden fresh-water which not only prevents stagnation but also enriches the land for agriculture purposes."

In Bihar the bunds on certain rivers were removed under instruction from the then Chief Engineer, Irrigation, Mr. Hall.

After full trial on bunds in India the policy of abandonment wherever possible of the embankment was taken up.

Iraq's experience.—Euphrates and Tigris rivers in Iraq have been embanked. Since the bunds are very high, they breach very often. By-pass channels, and spillways are also advocated besides the bunds upto a certain height. In the last decade as a flood control measure the large volume of Euphrates have been diverted into Habbaniyah Lake situated on the right side of the river. The work in a small quantity is again taken out of the lake of the lower end and dropped into the river. Thus a large reach of the Euphrates river is safeguarded against floods.

China's experience.—On the Yellow river in China large levees have been built from very old times. These have been raised from time to time and they have breached also occasionally. Recently the policy of depending solely on levees only has been abandoned. In 1954 in the reach of Yellow river known as Chinkaag river reliance has been placed upon the leeves upto a certain height say of 20 to 25 ft. A substantial part of the flood discharge has been diverted into a detention basin of a capacity of 5,500,000,000 M^3. The main dykes repaired and reinforced were 133 KM, the length of the intake and control structure were 1054 and 337 M. The main feature of the project was the detention basin.

It is evident anywhere from a perusal of the history of WORKS CONSTRUCTED IN DIFFERENT COUNTRIES that embankments, levees and bunds are invariably breached during high floods.

Recently very important levee lines which are also used as Highways became breached, overtopped or washed away. In 1950 the levee system on Red river during high floods collapsed and brought about major catastrophe. In 1953 levee lines maintained on Po river, Italy, gave way. Very elaborate flood dykes on the coast of Holland were badly breached causing colossal damage during the severe storm in 1952. This storm washed away levee lines on the coast of England also. Thus it appears from the study of the behaviour of these works that the levee lines in no case survived intact during high flood discharges. These collapsed or breached when they were needed to give protection. Since it is only during high floods that the levee lines are called upon to function and if they fail during this period they are of no use at all. In low flood stages the levee lines are not very much required. If it is allowed to spill over the countryside it is advantageous. The adoption of levees or embankments as a sole measure against flood control should be seriously reconsidered. During the recent floods, unprecedented in the history of Punjab, very high levee lines of proper specification and suitable section with adequate free board were badly smashed. This happens in the case of long embankments on the left bank of Ravi river. A similar embankment on the right bank of Yamuna river was also smashed. It may, therefore, be concluded that complete reliance on embankments should not be placed. This should be relied upon upto a certain height. Thereafter other measures should also be adopted. Each case shall have to be thoroughly investigated for devising a combination of measures.

The author during the past five years investigated this problem in certain details and came to the conclusion that on any river the creeks and defined spill channels taking off from the river should be closed with suitable bunds. The general spill over the normal surface should not be stopped. Stopping the deep spill channel has a healthy influence on the deepening of river channel and the normal spill over the land is welcome by the land-owners and they don't like to stop it. In pursuance of these plans 16 spill channels were closed on the Yamuna river in 1953. Each spill channel varied in width from 500 to 1,500 ft. and the depth was about 5 to 6 ft. in each case. These channels after taking off from the river proceeded towards villages and towns and inundating them for a distance of several miles. Two bunds were constructed on each spill, one about 1,000 ft. beyond the river edge and the other 2,000 ft. beyond the river edge. In the event of the failure of one bund, the second bund will help. This system has behaved very nicely during the last two years' flood and also in the recent unprecedented flood. The first bund has in certain cases been damaged

but this has deposited lot of silt. At a small cost the first series of bunds, which were damaged during floods, have been repaired and are functioning properly. Similarly bunds were constructed to close the creeks at Nagra on Yamuna river and on Ravi river at Narot Jaimal Singh. While the Nagla Bund was an earthen embankment, the Narot Jaimal Singh bund was a stone-pitched one. These bunds also have stood very well excepting that some damage occurred to a certain portion of the bund during the last unprecedented flood. A similar bund was constructed in 1954 to close the creek of the Sutlej river in the Bet area at Bahminian near Nakodar. This creek protected a very large number of villages and fertile valley. The earthen embankment pitched with stone in crates at the ends only was constructed at a small cost. This has worked very well and no damage has occurred even during the unprecedented floods. An important result of these full-scale experiments is that deep spill channels can be closed by constructing short bunds. In the past it had been thought that it was only a continuous bund over a long length and tied to high points which could stand. At the most what may be required is that the ends of the bunds may be pitched with pilchhi, matresses or stone crates and then the bund can be left only extended 200–300 ft. beyond the banks of the creeks. No marked erosion occurs at the ends of the bund. The bunds would continue to function unless they are badly overtopped. If the damage from the deep spill channels is stopped by closing the channels, the general overflow during high floods may take place. This does not cause much damage. It rather supplies manurial silt which is an advantage to the Zamindar.

A Combination of Measures for Flood Control

It is always advantageous to have a combination of measures for flood control rather than of flood problems. The author has been engaged on some of these problems.

The combination of measures may consist of the following:—

(i) Bunds, embankments or levees to a certain height.

(ii) Channel improvement by removing obstruction and making cut-offs.

(iii) Detention basins and flood control reservoirs.

(iv) By outlets, by-pass channels and floodways.

(v) Soil conservation.

In all large flood control problems all the different measures have to be investigated and whatever help can be obtained economically by different

measures in controlling floods should be taken. This is the modern method of affecting the flood control. Based on this, work had been carried out on large flood control problems during the last 10 to 15 years.

FLOOD PROBLEM ON EUPHRATES RIVER NEAR HABBANIYA, IRAQ

The problem was referred to author in 1944 for investigation with the help of models. The Euphrates river near Habbaniya (Iraq) in large and sudden floods raises the bed or the water flood level is headed up against the general valley land and is confined between levee lines. The river has short loops and meanders heavily. The levee lines, therefore, have also been built on curves. Frequent breaches occur in the embankments flooding valley land, causing heavy damage to land, property, cattle and human lives. A large sum of money had been spent for controlling the river by strengthening the embankment and adopting the stone and steel revetments, but no satisfactory solution was derived. Different measures were examined on large-scale hydraulic model at the Hydraulic Research Station, Malakpur. A long reach of the river together with the valley land in the Habbaniya lake was represented on the model. Of all the measures investigated including the dykes, spur training, the most suitable one found to be was ' withdrawal of water ' from the river in large quantity during floods and putting into the Habbaniya lake and again discharging into the river from the lake in a small volume. About 60,000 c.ft. per second was withdrawn from the river near Ramadya above Habbaniya and discharged into the lake through a lined channel. Since Habbaniya lake is very big, the rise in the lake level was not very appreciable. A special Head Regulator was constructed in the river. Similarly a regulator was constructed at the end of the lake for discharging the water back into the river. The outlet channel was a small one carrying 2,000 to 3,000 cs. discharge. This was for winter irrigation from the river. The scheme worked very satisfactorily. It is understood that this scheme has been executed at site and has worked satisfactorily. The natural detention basin has been utilised in this case. The loop of the river below the head regulator of the diversion channel has been immune against flood damages.

FLOOD CONTROL ON THE JHELUM RIVER IN KASHMIR VALLEY

The problem of the control of floods on the Jhelum river in the Kashmir valley was referred to author in 1950. The site was inspected and all the available data at the various places were collected and analysed. The river behaviour for the past 50 years was studied. The river was embanked there from earlier times. The embankments were constructed by the land-holders along the river Jhelum and later on this work was taken by the Government.

In spite of heavy expenditure on maintenance, the river bunds breached during the high floods and caused colossal damage to the valley land, property, cattle and human lives. The breaches occurred mostly from certain specific points. These bunds had been pitched with stone. In spite of that it was not possible to control the floods within the embankments. The river carries the flood discharge of 80,000 cs. while the capacity of the stream near Srinagar is not more than 40,000 cs. The flood control problem in this valley is a unique one. The measures to protect the valley land against the danger of inundation of the city of Srinagar were proposed. After thorough study it was decided to adopt measures for the control of floods on Jhelum river by (i) raising of banks upto a certain height, (ii) channel improvement and (iii) closing of torrents, diversion of tributaries, supplementary floodways or by-pass channels. A book entitled *Flood Control, Drainage and Reclamation in Kashmir Valley* has been written by the author and is under print with Central Water and Power Commission. The most important measure proposed was the taking off the supplementary channel (for the discharge of the river) about 30 miles below Srinagar. This channel where it was running was excavated, but where the channel has passed through the Jheels, Numbals and lakes periphery bunds have been raised.

This was as a reclamation measure also. The silted water was taken off from the river and the channel was given the steeper slope in the main. Silt was allowed to be deposited. The full cost of project is 3½ crores. The Chairman, Central Water and Power Commission, and the officers of C.W.P.C. have scrutinized the scheme. The scheme as finally evolved is being executed since 1954.

Flood Control on Yellow River in China

Based on the detention basins for flood control, the Chinese Engineers have diverted a large quantity of water from the Chinkaag Yellow river into the plains. They have relied on the levees upto 25 ft. This basin was constructed in 1954 and is expected to work satisfactorily. Simultaneously with the flood control measures on the plains, soil conservation measures on extensive scale were also taken up. Since the basin is large it would take quite a long time to silt up. For this period at least this scheme will give adequate protection.

Necessity of Investigation

Each case has to be investigated in detail prior to taking up the execucn of work. The floods of 1927 in the United States though caused very

extensive damage yet also resulted in one good, *viz.*, investigations by the Miami Conservancy District into the causes of the flood and measures to control these were undertaken. These investigations were very valuable to the Engineering profession. Another outcome of the devastating floods of 1927 in the United States of America was the establishment of Waterways Experimental Station at Vicksburg, where flood control problems were to be investigated with the help of hydraulic models.

India possesses a few large Hydraulic Research Stations where problems on flood control on various rivers can be satisfactorily examined. Each big project should be tested and finalized before undertaking the entire work.

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